
Andrew L. Drozd Dr.
adrozd@androcs.com

Follow this and additional works at: https://fisher.pub.sjfc.edu/education_etd

Recommended Citation

Please note that the Recommended Citation provides general citation information and may not be appropriate for your discipline. To receive help in creating a citation based on your discipline, please visit http://libguides.sjfc.edu/citations.

This document is posted at https://fisherpub.sjfc.edu/education_etd/469 and is brought to you for free and open access by Fisher Digital Publications at St. John Fisher College. For more information, please contact fisherpub@sjfc.edu.

Abstract
STEM (science, technology, engineering, and mathematics) has gained significant notoriety and momentum in recent years. STEM literacy highlights the vital connection between an educated STEM workforce and U.S. national prosperity and leadership. STEM educational and job placement goals have been a national priority for over the past 20 years. However, the STEM gap is widening—contributing to increasing STEM pipeline leakage and the social injustice milieu of a noncompetitive workforce—undermining efforts to create prosperity and sustain global leadership. The pace of STEM jobs filled lags the rate of technological advancement and the surges in skilled STEM labor demand. The aggregate disparity over time has troubling implications. The purpose of the study was to examine the STEM gap touchpoints for a Central New York high school during the transition period upon entering college or the workforce. A qualitative case study used Lesh's translation model as a research framework. A semi-structured, focus group protocol was employed to gain a fresh perspective on the STEM gap problem and identify purposeful interventions. A major finding was the slow pace of adopting institutional reforms that replaces standardscompetency-based learning with progressive application- and outcome-based pedagogy. The study has implications for school districts, secondary schools, and higher education teacher preparedness programs in STEM pedagogy and curriculum development. A knowledge-based, progressive STEM theoretic framework with pedagogical scaffolding is conceptualized rooted in artificial intelligence and machine learning. The study presents recommendations for school districts, secondary education teachers, state education and legislative leaders, higher education institutions, and future research.

Document Type
Dissertation

Degree Name
Doctor of Education (EdD)

Department
Executive Leadership

First Supervisor
C. Michael Robinson, Ed.D.

Second Supervisor
Andrew Turner, Ed.D.

Subject Categories
Education

This dissertation is available at Fisher Digital Publications: https://fisherpub.sjfc.edu/education_etd/469
A Case Study on the Efficacy of STEM Pedagogy in Central New York State:
Examining STEM Engagement Gaps Affecting Outcomes for High School Seniors and
Post-2007 Educational Leadership Interventions to Reinforce STEM Persistence with
Implications of STEM Theoretic Frameworks on Artificial Intelligence / Machine Learning

By

Andrew L. Drozd

Submitted in partial fulfillment
of the requirements for the degree
Ed.D. in Executive Leadership

Supervised by
C. Michael Robinson, Ed.D.

Committee Member
Andrew Turner, Ed.D.

Ralph C. Wilson, Jr. School of Education
St. John Fisher College

December 2020
Dedication

This dissertation is dedicated to my son Evan, who at the time of this work had completed his undergraduate degree in the biological sciences and pre-medicine, and who inspired me throughout the doctoral education process. We became scholars together. He encouraged and uplifted me when I needed it. I hope I inspired him as well. I further dedicate the dissertation to my wife Barb, who provided support and encouragement.

The dissertation is also dedicated in large part to my parents Maria and Matthew who are forever in my thoughts and prayers. They taught me to work hard, persevere, and achieve to the best of my ability. Hopefully, I met their expectations, and they are looking kindly on me and are proud of my accomplishments. Without them I would have been unable to accomplish what I did in life, work, education, and in all things.

I dedicate the dissertation in part to my committee and thank them for their guidance and mentorship over the past 3 years. They helped me to develop scholarly research skills and I am very grateful to them for all their support. I want to additionally thank my C the Future team and Cohort 5 for their support, friendship and fellowship, and everything they taught me. My life has been enriched because of them. I also thank Saint John Fisher College for sponsoring a program that taught me to lead confidently and be mindful of the importance of social justice in our world. I have been enriched by the DEXL vision of executive leadership and evangelism for social justice, and it has profoundly changed me for the better. Last but not least, I thank God for answering my prayers. I have arrived at a destination that I thought could not be reached.
Biographical Sketch

Andrew L. Drozd is currently the president/CEO and chief scientist at ANDRO Computational Solutions, LLC and the executive director of the nonprofit Project Fibonacci Foundation, Inc. dedicated to STEM (Science, Technology, Engineering, and Mathematics) leadership. He is a 44-year veteran scientific researcher, technology innovator, executive leader, and business entrepreneur. Mr. Drozd attended Syracuse University from 1974 to 1977 and graduated with a Bachelor of Sciences degree in Physics and Mathematics in 1977. He attended Syracuse University from 1978 to 1982 and graduated with a Master of Sciences degree in Electrical Engineering in 1982. He enrolled at St. John Fisher College in the spring of 2017 and began doctoral studies in the Ed.D. Program in Executive Leadership. Mr. Drozd pursued his research in progressive STEM pedagogy with implications to artificial intelligence and human/machine learning using a STEM theoretic framework under the direction of Dr. C. Michael Robinson, Dr. Kim VanDerLinden, and Dr. Andrew Turner and received the Ed.D. degree in 2020.

Mr. Drozd is a Fellow of the Institute of Electrical and Electronics Engineers (IEEE) since 2002 and served as president of the IEEE Electromagnetic Compatibility Society (EMCS) from 2006 to 2007. He was inducted as an Honorary Life EMCS Member in 2007 and is certified by the International Association for Radio and Telecommunications Engineers. His work has examined the role of artificial intelligence in communications. He plans to continue research for journal and book publications that would inform the field of artificial intelligence in STEM learning theoretic frameworks.
Acknowledgements

ANDRO Computational Solutions, LCC and the Project Fibonacci® Foundation, Inc. are acknowledged for their joint organizational support of the research described in this dissertation and towards the researcher’s professional development. ANDRO supported the research described on behalf of STEM workforce preparedness and STEM job creation. The Project Fibonacci® Foundation supported the research through two field experience tours in 2018 and 2019 for the purposes of increasing STEAM leadership education for K-college students and to enable STEAM career development pathways.

The researcher also wishes to thank ANDRO for its ongoing fiscal support and the Project Fibonacci® Foundation for the many resources it provided in support of two field experiences and related academic studies. The findings of the study will be shared with both organizations to assist in their respective STEM recruitment and community leadership development initiatives. It is anticipated that the findings of the study will help guide future research projects for the purposes of extending the results and the insights gained.
Abstract

STEM (science, technology, engineering, and mathematics) has gained significant notoriety and momentum in recent years. STEM literacy highlights the vital connection between an educated STEM workforce and U.S. national prosperity and leadership. STEM educational and job placement goals have been a national priority for over the past 20 years. However, the STEM gap is widening—contributing to increasing STEM pipeline leakage and the social injustice milieu of a noncompetitive workforce—undermining efforts to create prosperity and sustain global leadership. The pace of STEM jobs filled lags the rate of technological advancement and the surges in skilled STEM labor demand. The aggregate disparity over time has troubling implications.

The purpose of the study was to examine the STEM gap touchpoints for a Central New York high school during the transition period upon entering college or the workforce. A qualitative case study used Lesh’s translation model as a research framework. A semi-structured, focus group protocol was employed to gain a fresh perspective on the STEM gap problem and identify purposeful interventions. A major finding was the slow pace of adopting institutional reforms that replaces standards-competency-based learning with progressive application- and outcome-based pedagogy.

The study has implications for school districts, secondary schools, and higher education teacher preparedness programs in STEM pedagogy and curriculum development. A knowledge-based, progressive STEM theoretic framework with pedagogical scaffolding is conceptualized rooted in artificial intelligence and machine
learning. The study presents recommendations for school districts, secondary education teachers, state education and legislative leaders, higher education institutions, and future research.
Table of Contents

Dedication .................................................................................................................................. iii

Biographical Sketch ................................................................................................................ iv

Acknowledgements .................................................................................................................. v

Abstract .................................................................................................................................... vi

Table of Contents ................................................................................................................... viii

List of Figures ........................................................................................................................ xi

List of Tables .......................................................................................................................... xiii

Chapter 1: Introduction ......................................................................................................... 1

  Introduction ......................................................................................................................... 1

  Problem Statement ............................................................................................................ 3

  Theoretical Rationale ....................................................................................................... 15

  Statement of Purpose ....................................................................................................... 23

  Research Questions .......................................................................................................... 26

  Potential Significance of the Study ................................................................................... 27

  Definitions of Terms ........................................................................................................ 29

  Chapter Summary ............................................................................................................ 31

Chapter 2: Review of the Literature ....................................................................................... 32

  Introduction and Purpose ............................................................................................... 32

  STEM’s Origins—A Foundational Overview ................................................................... 33

  STEM Pedagogy and Learning Protocols ....................................................................... 47
# Table of Contents

- Introduction ................................................................................................................. 358
- Implications of Findings ............................................................................................. 363
- Limitations .................................................................................................................. 389
- Recommendations ....................................................................................................... 391
- Conclusion .................................................................................................................. 417
- References ....................................................................................................................... 431
- Appendix A ..................................................................................................................... 453
- Appendix B ..................................................................................................................... 457
- Appendix C ..................................................................................................................... 461
- Appendix D ..................................................................................................................... 465
- Appendix E ..................................................................................................................... 468
- Appendix F ..................................................................................................................... 471
- Appendix G ..................................................................................................................... 475
**List of Figures**

<table>
<thead>
<tr>
<th>Item</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 1.1</td>
<td>Relative average PISA scores in science, mathematics, and reading in 2015 compared to all countries worldwide</td>
<td>8</td>
</tr>
<tr>
<td>Figure 1.2</td>
<td>PISA average scores and changes in average scores of sample U.S. student population</td>
<td>9</td>
</tr>
<tr>
<td>Figure 1.3</td>
<td>Relative percentage of total STEM and total non-STEM students in colleges and universities nationwide that switch from their original declared field of study.</td>
<td>10</td>
</tr>
<tr>
<td>Figure 1.4</td>
<td>Percentage of women’s degrees in STEM fields</td>
<td>12</td>
</tr>
<tr>
<td>Figure 1.5</td>
<td>The LTM showing five modes of representation and translations between or within them</td>
<td>19</td>
</tr>
<tr>
<td>Figure 1.6</td>
<td>The STEM translation model (with math at the center) as the combination of the individual disciplines along with the translations that connect them</td>
<td>20</td>
</tr>
<tr>
<td>Figure 2.1</td>
<td>Functional areas of the brain showing how the various monitoring, management, and control functions are allocated</td>
<td>92</td>
</tr>
<tr>
<td>Figure 2.2</td>
<td>Perry’s neurosequential model showing the progression of a child’s neural development and its impact on behaviors including effects on learning capacity</td>
<td>93</td>
</tr>
<tr>
<td>Figure 4.1</td>
<td>How to motivate your team with Maslow’s hierarchy of needs</td>
<td>158</td>
</tr>
<tr>
<td>Figure 4.2</td>
<td>The fixed mindset versus the growth mindset</td>
<td>198</td>
</tr>
<tr>
<td>Figure 4.3</td>
<td>Carol Dweck revisits the 'growth mindset'</td>
<td>277</td>
</tr>
<tr>
<td>Figure 4.4</td>
<td>The “Inspiring Action” visual from Alberta Education is used to assess many initiatives in schools</td>
<td>278</td>
</tr>
<tr>
<td>Figure 4.5</td>
<td>The Inspiring Education Wheel</td>
<td>279</td>
</tr>
</tbody>
</table>
Figure 5.1  The STEAM translation pyramid (with math and non-STEM at the center) as the combination of the individual disciplines along with the translations that connect them  372

Figure 5.2  STEM prism using artificial intelligence and knowledge-based methods to generate optimized STEM guidance as customized programs, curricula, and recommendations  406
## List of Tables

<table>
<thead>
<tr>
<th>Item</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table 3.1</td>
<td>ESM High School Institutional Demographics</td>
<td>126</td>
</tr>
<tr>
<td>Table 4.1</td>
<td>Research Question A Priori Codes and Convergence (STEM Student Perspective)</td>
<td>149</td>
</tr>
<tr>
<td>Table 4.2</td>
<td>Research Question A Priori Codes and Convergence (STEM Educator Perspective)</td>
<td>150</td>
</tr>
<tr>
<td>Table 4.3</td>
<td>Profile of Focus Groups</td>
<td>155</td>
</tr>
<tr>
<td>Table 4.4</td>
<td>STEM Gap Factors, Trends, and Relevant Research Questions (Students and Educators)</td>
<td>286</td>
</tr>
</tbody>
</table>
Chapter 1: Introduction

Introduction

Bybee (2010) defined STEM (science, technology, engineering, and mathematics) pedagogy as a broad, coordinated strategy for precollege education that should include all the STEM disciplines. He pointed to the need for “greater diversity in the STEM professions, for a workforce with deep technical and personal skills, and for a STEM-literate citizenry prepared to address the grand challenges of the 21st century.” Bybee further stated that

True STEM education should increase students’ understanding of how things work and improve their use of technologies. STEM education should also introduce more engineering during precollege education. Engineering is directly involved in problem solving and innovation, two themes with high priorities on every nation's agenda. (p. 996)

Wu-Rorrer (2017) on the other hand defined STEM education as the integration of the individual disciplines into a single meta-discipline and establishing the connections between the curriculum content and the students’ real-world experiences. Jacobs (1989, p.8) much earlier posited that an interdisciplinary curriculum “consciously applies methodology and language from more than one discipline to examine a central theme, issue, problem, topic, or experience.” White (2014) reinforced the idea that integrative and collaborative STEM learning will help K-12 students to better embrace STEM and could inspire the pursuit of a STEM major in higher education and ultimately a STEM
career. Similarly, “STEM Curricula” (2017) reiterated a definition of STEM education based on a curriculum that integrated two or more of the STEM disciplines. Merrill (2009) offered a definition of an ideal implementation of STEM education as

A standards-based, meta-discipline residing at the school level where all teachers, especially science, technology, engineering, and mathematics (STEM) teachers, teach an integrated approach to teaching and learning, where discipline-specific content is not divided, but addressed and treated as one dynamic, fluid study. (p. 2)

Of greater importance though, is STEM engagement. The term engagement refers not only to engaging one’s interest in STEM subjects, but how engagement can be used to reinforce persistence in STEM fields and careers to close the STEM gap. Bell (2009) further defined STEM engagement as a process of considering how two groups (educators and students) should interact. Bell focused on methods for effective science communication to generate interest in technical subjects through professional engagers, effective delivery methods, community networks, institutional resources, and previous learning activities or experiences. Bell also considered the application of progressive or forward-leaning thought that embraces the role and contribution of multiple disciplines. The strategy starts by assuring clear and concise science communication and acquiring a granular knowledge of how multiple disciplines share common mathematical threads.

Indeed, Colegrove (2017) and Grant and Patterson (2016) purported that STEM learning inclusive of the arts, or STEAM, may be an effective STEM engagement device. On this theme, Payton, White, and Mullins (2017) examined the experiences of college students who were enrolled in an interdisciplinary STEM and arts curriculum with a
focus on dance art. The students cited similarities between the art of dance and STEM problem-solving approaches that involved collaboration and the critical thinking ethos of the college experience. Based on their findings and observations, opportunities were identified to reframe current engagement strategies to widen STEM interest and participation using the arts as a possible enabler. Grant and Patterson claimed that the arts animated learning via an experiential process that stimulates creativity and critical thinking, which are equally valued in STEM pedagogy; although, the arts have not been traditionally part of interdisciplinary STEM education, thus highlighting a bridge-learning gap that otherwise could be a useful device for enhancing STEM engagement.

The dissertation will present representative examples that examine how leveraging the arts, such as music, can influence STEM engagement through modified educational strategies or interventions. Notwithstanding, extenuating circumstances continue to plague STEM engagement strategies and practices. The inherent challenges are deeply rooted in the “how” and “why” of STEM education delivery today. Irrefutable evidence exists on STEM engagement gaps and the need for interventions to reinforce STEM persistence outcomes as discussed next.

**Problem Statement**

STEM, unknown by the acronym at the time, has been on the national agenda since the Reagan administration. STEM began its rise to prominence during George H. W. Bush’s administration and soared to the top of the national agenda during George W. Bush’s term in office. Every president since then has identified STEM as a national priority and has set specific educational STEM goals to drive job growth and fuel the U.S. economy.
The emergence of smart devices like the Apple iPhone in 2007 ignited a
technology boom that launched the modern age of STEM perhaps even more profoundly
than the Internet did during the 1990s and increased demands for STEM proficiency
(Drozd et al., 2017; Gonzalez & Kuenzi, 2012; Lazio & Ford, 2019; National Science
Foundation, 2014; White House, 2009). The technological surge continues to this day
with the increasing ubiquity of smart devices (Drozd et al.). According to the White
House however, to sustain the technological growth in the modern age requires the U.S.
government, businesses, and academic institutions to adopt a progressive STEM agenda
and to launch an aggressive STEM campaign nationwide. Over the intervening years
since 2007, a wide variety of STEM programs and interventions were trialed to expand
the STEM pipeline but were met with limited success (Drozd et al., 2017; National
Science Foundation, 2014). Consider the background perspectives as follows.

Gonzalez and Kuenzi (2012) reported that STEM programs have gained
momentum, expanding into pre-K-12 schools and colleges to meet industries’ demands
for a prepared, agile, and globally competitive 21st century labor force. They identified
the need for U.S. STEM literacy and workforce preparedness focusing on the relationship
between STEM readiness and national prosperity, power, and leadership. Gonzalez and
Kuenzi further claimed that the US performed poorly in STEM education despite efforts
to expand academic STEM programs over the past 20 years. They cited concerns over
the continuing academic performance gaps across student demographic groups, the lack
of STEM teacher preparedness, the mediocre standing of the US in international STEM
assessments, an outpacing in educational achievement by other countries, and the
inability of the U.S. STEM education system to fill domestic STEM workforce demands.
Sustained small business growth built on technological innovations fuels the U.S. economy and all but assures America’s role as a global leader in scientific research and development (R&D). Despite the significant STEM push, the outcome has been less than optimistic. The pace at which STEM jobs have been filled has significantly lagged the rate of scientific R&D growth and the surges in demand for skilled STEM labor. Strauss (2018) cited the results of a PayScale, Inc. survey that reported 60% of business leaders believed today’s college graduates lack the requisite skills for job placements pointing to another looming challenge.

In response to bleak forecasts, the U.S. government initiated programs and appointed task forces to address the STEM gap. The White House (2009) reported that the Educate to Innovate program was launched under President Barak Obama to inspire young students across America to step up and be part of a “world class STEM workforce” (p. 4). Since his first term in office, President Obama reinforced his “commitment to raise America from the middle to the top of the pack internationally in STEM education over the next decade” (p. 4). Despite such programs, the number of unfilled STEM jobs across the US continues to grow and STEM-based entrepreneurial startups have curtailed in recent years (Drozd, et al., 2017; “STEM Curricula,” 2017).

Lazio and Ford (2019) reported that millions of STEM jobs in the US remain vacant. They claimed that the true number likely exceeds 8.6 million STEM job vacancies representing approximately 6.2% of employment in the US. By 2027, the number of STEM jobs was projected to grow 13% and the gap is anticipated to further widen. U.S. federal agencies have conservatively forecasted an estimated shortage of some one million STEM workers through 2026, an indication of STEM pipeline leakage.
that jeopardizes sustainable growth of the STEM workforce and that will negatively impact the U.S. economy (Iammartino, Bischoff, Willy, & Shapiro, 2016).

According to the Smithsonian Science Education Center (2020), the number of STEM jobs since the Industrial Revolution has doubled as a proportion of all jobs in the US with a three-fold rate increase in STEM-related jobs over non-STEM jobs between 2000 and 2010. The Center reported that nearly 2.4 million STEM jobs went unfilled through 2018. It also reported that minorities were significantly underrepresented and disaffected in STEM fields—the implication being that minorities lacked the necessary qualifications to compete for STEM-related jobs, which were not only more plentiful but also better paying than non-STEM jobs in many cases by 12% to as high as 30% across all education levels. OPM.gov (2019) reported only 13% of the total U.S. federal workforce between 2005 and 2014 were STEM workers with little to no improvement in sight per today’s economic indicators. Wiebe et al. (2013) cited a significant lack of STEM career awareness and pathways to STEM job opportunities available to students as reasons for the growing STEM gap.

According to Lazio and Ford (2019), the troubling STEM downtrends have prompted the Trump administration to prompt the creation of nearly 3.5 million STEM jobs by 2025, but there is no clear plan in place to effectively sustain the STEM pipeline to meet the projected demand. Today, nearly 60% of employers are having difficulty filling STEM job openings in a timely way because of a critical skills gap. The gap points back to the education system and the quality and efficacy of existing STEM programs. Additionally, STEM program modernization or reform has not consistently kept pace with technological advancements that inform future occupations. Pethohoukis
(2018) estimated that 65% of today’s elementary students will wind up working in STEM occupations that do not exist today that include advanced artificial intelligence fields.

The National Science Board (2018) reported that in 2015, 25% of high school seniors achieved a level of proficiency in mathematics with only 22% achieving a level of proficiency in science per the National Assessment of Educational Progress (NAEP) evaluations. The Board further reported that significant sociocultural and socioeconomic inequities exist limiting opportunities for higher education study and careers in STEM.

Ravitch (2010, p. 286) pointed out that children from affluent families had the highest academic scores where the opposite was true of children from poverty-stricken families or impoverished communities on past Program for International Student Assessment (PISA) tests. Indeed, the STEM education gap is a multifaceted issue.

A Pew Research Center report (2017) stated that the US fell in the middle of the 2015 PISA test scores in science, math, and reading compared to all other countries around the world, as shown in Figure 1.1. The published Pew report ranked the U.S. students 40th worldwide in math literacy. The International Activities Program National Center for Education Statistics (2015) further cited a decline in math aptitude during the prior two assessments where the U.S. students fell below the math baseline proficiency level, revealing a gap between the national STEM push and demonstrated proficiencies or outcomes. According to the report, the U.S. score was 23 points below the average of all nations that participated in the 2015 survey and where 29% of U.S. students fell below the math baseline proficiency level; furthermore, the U.S. students’ rankings in science (25th) and reading (24th) remained relatively flat compared to previous years. According to the 2015 surveys, Singapore surpassed all nations in all categories. The other top
countries that outperformed the US were China, Japan, Korea, Canada, Switzerland, Estonia, Australia, and New Zealand. The aggregate results from 2000-2015 are summarized in Figure 1.2, bearing out a strong disconnection between the national STEM push and demonstrated proficiencies. The disturbing trend can have a profound impact on long-term U.S. STEM career development and international competitiveness.

The most recent PISA findings confirmed that the STEM gap problem persists (Camera, 2019; International Activities Program National Center for Education Statistics, 2018; OECD iLibrary, 2020). According to Camera (2019), the most recent PISA scores for U.S. students in science and reading were marginally above average and in mathematics were marginally below average, thus showing no significant change since
the prior-years’ performance ratings. Camera also noted that 30 countries outscored the
U.S. students in math and that the gap is widening between the top and lower performers.
PISA, developed by the Organisation for Economic Cooperation and Development (OECD)—an intergovernmental consortium of 37 mostly industrialized countries, is
administered every 3 years to more than 600,000 students in 79 countries and continues to
provide useful benchmarks to measure STEM-based proficiencies. Unfortunately, for
U.S. students virtually little to no progress has been made for nearly the past 20 years—a
finding that the STEM community finds troubling and that exacerbates concerns over the
STEM gap problem.

<table>
<thead>
<tr>
<th>National Center for Education Statistics</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Subject</th>
<th>2000 Average score</th>
<th>2003 Average score</th>
<th>2006 Average score</th>
<th>2009 Average score</th>
<th>2012 Average score</th>
<th>2015 Average score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Science literacy</td>
<td>481.4</td>
<td>483.2</td>
<td>500.3</td>
<td>497.3</td>
<td>498.7</td>
<td>493.2</td>
</tr>
<tr>
<td>Reading literacy</td>
<td>495.3</td>
<td>496.3</td>
<td>500.3</td>
<td>497.3</td>
<td>497.3</td>
<td>497.3</td>
</tr>
<tr>
<td>Mathematics</td>
<td>2.9</td>
<td>4.0</td>
<td>4.0</td>
<td>3.6</td>
<td>3.6</td>
<td>3.2</td>
</tr>
</tbody>
</table>

Additional findings include:

- Nearly 78% of high school graduates fell short of meeting “readiness benchmark levels”
  for freshman college courses in mathematics, science, or reading yet the demand for
STEM talent continues to grow. Approximately 35% of all STEM majors in U.S. colleges and universities change to a non-STEM course of study at least once within their first 3 years as shown in Figure 1.3. Whalen and Shelly (2010) provided further compelling and disturbing evidence of the challenges in sustaining STEM interest citing a steady erosion of U.S. college students who switch from STEM to non-STEM majors.

Bruce-Davis et al. (2014) and Wu-Rorrer (2017) suggest that the sustainment strategy to integrate STEM into the pre-K-12 educational system is a work in progress and no single strategy exists, which may explain why the US has fallen behind other nations in global STEM leadership. The U.S. STEM pipeline shows evidence of significant stress and depleted capacity. The STEM engagement gaps are widening, contributing to declining trends in persistence and increasing STEM pipeline leakage.

Jagoda, Gilliam, McDonald, and Russell (2015) cited a lack of diversity in STEM education as contributing to representational imbalances, reduced job/career opportunities...
for underrepresented or disaffected groups, and limited innovation potential. Indeed, gender bias, stereotype threats, and a fear of STEM especially in the case of females, where women comprise over half of the U.S. population, present major challenges to STEM engagement and persistence. For instance, the National Science Foundation (2015) reported that nearly 80% of females in the US are underrepresented in STEM undergraduate degrees.

The National Science Foundation (2014) also reported that since the year 2000, the number of bachelor’s degrees earned by women fell by 10% in computer sciences, 5% in mathematics, 2% in physics, and 2% in engineering as shown in Figure 1.4. Furthermore, nearly 75% of women turn down STEM careers compared to their male counterparts who hold the most of such careers (Drozd et al., 2017). The U.S. labor force agencies have sought to increase the ranks of women in STEM professions to foster equal opportunity, social mobility, and economic progress and reverse the overall decline of STEM careers. Yet according to Drozd et al., in New York State alone, over 140,000 STEM jobs remained unfilled and similar trends can be found in other states nationwide.

Another factor affecting STEM engagement and persistence is the type of STEM education options or offerings available to students in pre- and post-secondary institutions, and especially for underserved student groups. Van Noy and Zeidenberg (2017) examined the impact of 2-year community college STEM certifications versus 4-year university STEM degrees on long-term engagement. Their study showed that 2-year community colleges play a significant role in preparing underrepresented students for the STEM workforce in science and engineering (S&E) and technician certification programs, including subsequent transfer to a 4-year institution for additional training.
Van Noy and Zeidenberg (2017) stated that community college STEM students tended to be older and “more likely to be first-generation college students” compared to their younger STEM counterparts entering a 4-year institution (68% versus 38%, respectively); furthermore, 2-year students tended to enroll part-time while seeking outside employment. However, the completion rates were low for older students when transferring to a 4-year institution because of the high tuition costs and especially if they were already employed. Similar trends across the US have contributed to an overall persistence gap in the STEM labor force.

Bozick, Srinivasan, and Gottfried (2017) performed a complementary study where they hypothesized a forward association between a student’s exposure to advanced
or applied STEM curricula in secondary schools and the ability of non-college bound youth to successfully transition to the STEM workforce within 2 years of high school graduation. No evidence was found to support the hypothesis after surveying a nationally representative number of 15,362 students who were randomly sampled using data from the Education Longitudinal Study of 2002 (ELS:2002) courtesy of the National Center for Education Statistics (NCES). Their findings indicated that high school STEM coursework had no direct bearing on securing a STEM job 2 years after graduation.

Using a classification scheme developed by the Brookings Institution, Bozick, Srinivasan, and Gottfried (2017) found that approximately 10% of the non-college bound youth held such jobs within 2 years of graduating high school. They concluded that (a) employers were more apt to hire students with the proper STEM skills and training; (b) a gap exists in national federal and education policy to prepare all youth for STEM careers—including those not transitioning to college; and (c) the curricula offered in America’s high schools were not positively contributing to the STEM labor pool. The findings highlight a troubling trend that negatively impacts the STEM pipeline.

All factors considered, the STEM persistence problem remains two-fold. First, an apparent gap exists in STEM engagement from the time of high school to when one enters college or the workforce. Secondly, STEM pedagogy has been largely delivered in traditional, siloed, lecture-based classroom settings making it less engaging to students. Such an educational approach often fails to take full advantage of methods and protocols designed to enhance the STEM learning experience and engage students’ interests.

Newer, more progressive methods and protocols have emphasized active, constructivist problem-based learning that taps into real-world applications (Smith,
Douglas, & Cox, 2009). Other strategies have included ways to incorporate career awareness education in STEM lessons (Reiss & Mujtaba, 2017). Notwithstanding, the problem is that STEM engagement gaps continue to widen, contributing to declining trends in STEM persistence and increasing STEM pipeline leakage, thus eroding our national agenda to create prosperity and sustain our nation’s power and position as a global leader. Moreover, the problem is adding to the social injustice milieu by denying opportunities for our youth to compete internationally for high-paying STEM jobs and pursue rewarding lifelong STEM careers.

The research problem, therefore, is to identify and investigate the root causes of STEM pedagogic gaps and to determine if and how various strategies such as integrated, interdisciplinary active learning interventions or career awareness training in STEM education can increase STEM engagement/persistence in high schools. The initial focus is on high schools in the Central New York State (CNY) region. Integrated, interdisciplinary STEM learning can be used to exploit the synergies (interrelationships) between the individual components of STEM and can be extended to encompass non-STEM subjects (Glancy & Moore, 2013). To that end, the dissertation research explored the synergies between the individual STEM disciplines and music (as an engagement device) via a common mathematical scaffolding or framework.

The research problem raises an important leadership imperative regarding the development and delivery of future high school STEM curricula. The imperative is to closely explore the bridge between science and the fine arts for preservice and in-service teacher preparedness and administrator restructuring to foster programs that take advantage of the power of integrated, interdisciplinary learning as a paradigm shift to
close the STEM engagement/persistence gaps. In particular, the approach draws on the perspectives of educational leaders in college teacher preparation for high schools. Pedagogical and organizational social change theories provided a basis for paradigm shifts to meet the desired goals based on theoretical rationale as discussed next.

**Theoretical Rationale**

Theoretical models can provide a means of exploring ways to improve STEM engagement in high school by raising awareness of the subtle relationships between seemingly disparate disciplines made actionable through a progressive, pedagogical framework. Relevant extant theories have examined the many factors and processes that guide our understanding of the social system environments and micro-agent (individual human) interactions that produce an irreducible, complete macrosystem outcome on STEM engagement and persistence. Multiple studies and research initiatives have examined the nature of such macrosystem models and causalities for social system environments in educational and workplace settings.

For example, agent-based, system-based, social interaction, and social impact theories have been developed and proposed to address myriad STEM gap problems (Allen & Davis, 2010; Anderson, 1999; Basham, 2015; Charmaz, 2008; Eagleman, 2015; Emergence, 2017; Emergence, 2019; Golds & Kay, 2010; Haghnevis & Askin, 2012; Iammartino, et al., 2016; Latane, 1996; Quantum Gravity Research, 2017; Walker & Myrick, 2006; Wilson, Broughan, & Hillier, 2017). However, the studies failed to embrace a holistic view of the state of STEM engagement and persistence. The studies further overlooked a preponderance of evidence on the use of certain underlying theories that tap into the power of integrated, interdisciplinary synergies and micro-agent
interactions for STEM learning such as Lesh’s translation model (LTM) theory (Lesh & Harel, 2003).

The LTM is a core technical theory crucial to understanding and addressing the STEM gap problem. It establishes a theoretical framework that examines how individuals learn through awareness of the interdisciplinary relationships that exist between individual subjects such as the components of STEM. Taking this concept one step further, studying the interplay of non-STEM disciplines on STEM learning can reveal a broader set of relationships that lend to a granular understanding of how STEM and non-STEM domains are connected and how this knowledge can affect engagement.

Hence, the urgent nature of the STEM gap problem begs for the application of new engagement methods, change theories, and actionable strategies to STEM pedagogy. The application of a relevant theory begins with examining STEM learning environments and how STEM itself is taught. STEM learning environments refer to schools or classrooms that deliver educational content and conduct learning activities in at least two of the core STEM disciplines (Bell, 2009).

Oftentimes, however, STEM subjects are taught individually (segregated) in a traditional classroom setting instead of using an integrative STEM approach that emphasizes collaborative, project-based activities both inside and outside of the classroom. Although many schools have begun to abandon the traditional siloed STEM model, the preponderance of evidence shows that much more change is needed for effective integrated STEM curriculum to take root and improve STEM outcomes (Bruce-Davis, et al., 2014). Theories, such as LTM theory, play a crucial role in developing and executing the overall change strategy for improving outcomes.
Glancy and Moore (2013), drawing on LTM theory, suggest that the “process” of purposefully integrating the individual STEM disciplines unveils a set of theoretical, instruction-based, inherent relationships. Such relationships draw on (a) experiential education (what is learned through experience or trial and error); (b) concrete manipulatives (cognitively relating abstract concepts to physical objects and spatial awareness through hands-on learning); and (c) multiple representations as persistent ideas (instantiating concepts viewed in multiple dimensions or perspectives). Thus, an expanded view of how the individual STEM subjects interrelate via theoretic constructs can contribute to the efficacy and success of STEM instructional environments and educational delivery methods. As an exercise in critical thinking, examining the common mathematical relationships between topics in engineering and technology can reveal deeper insights into broader relationships that connect multiple, diverse subject areas (math as “glue”) as the relevant theories suggest.

Expanding instruction- and theoretic-based critical thinking along these lines produces multiple benefits. First, the approach can be used to (a) promote collaborative problem solving, (b) introduce realistic applications of STEM content, and (c) facilitate multiple frames of thought and subject matter entry points to key concepts enabling diverse expression of ideas in multiple modes of representation. Second, the approach expands opportunities for brainstorming and arriving at creative, innovative solutions in activities-based STEM learning. Dewey (1938), Dienes (1960), and Lesh and Harel (2003) provided the theoretical foundation for effective STEM learning as viewed through the lens of the LTM theory.
The present research explored changes to the traditional STEM model by leveraging the LTM and related theoretical constructs that promote interdisciplinary diversity and enable new frames of thought, curiosity, and inquiry leading to improved STEM engagement outcomes. Improved outcomes would support the social justice goals of equity, equal opportunity for high-paying STEM jobs, social mobility, competitiveness in innovation, skills development, economic prosperity, and life enrichment for all citizens. The application of the LTM theory to achieve these goals is discussed next.

**LTM theory.** The LTM theory conceptualizes STEM integration through an in-depth understanding of the relationships that exist between two or more of the underlying disciplines (Lesh & Harel, 2003). Using the semantic terms of Glancy and Moore (2013) and Lesh and Doerr (2013), the theory builds on the tenets of (a) multidisciplinary problem solving, (b) teamwork and collaboration, (c) interconnecting learning and personal experience, (d) multiple embodiments of a concept or experience (perceived viewpoints or micro views), and (e) representational fluency (articulating the perceived nature of things across multiple dimensions, frames of thought, or interpretations). In effect, the LTM theory provides a mechanism of breaking down the paradigm of disciplinary silos, thus sparking interest in external subjects and advancing education through enhanced interest, curiosity, and exploration. Lesh and Doerr described the LTM theory as a network consisting of five nodes where each node indicates distinct representations and the translations between or within those representations as illustrated in Figure 1.5.

Lesh and Doerr (2003) defined a translation as a mapping of a concept or knowledge-based embodiment from one representation to another as Figure 1.5 depicts.
Integrated STEM learning fits this approach. It can be thought of as an amalgam of the concepts, ideas, communicative skills, and higher-order reasoning that links the STEM disciplines expounding the notion that STEM is more than merely the sum of its parts, which is consistent with the tenets of emergent theory (Charmaz, 2008; Wilson, Broughan, & Hillier, 2017). An object, concept, or notion can be represented across multiple dimensions (symbolically written, diagrammed, orally expressed, using similarities or metaphors based on experience, and via physical or tactile manipulations).

![Figure 1.5. The LTM showing five modes of representation and translations between or within them. Adapted from “Foundations of a Model and Modeling Perspective on Mathematics Teaching, Learning, and Problem Solving,” by R. A. Lesh and H. M. Doerr, 2003. In R. A. Lesh and H. M. Doerr (Eds.), Beyond constructivism: Models and modeling perspectives on mathematics problem solving, learning, and teaching (pp. 3–33). Mahwah, NJ: Lawrence Erlbaum Associates.](image)

In the same way, the LTM theory provides a useful framework for acquiring a conceptual understanding of the interrelationships between and within the individual
STEM disciplines. Figure 1.5 can be modified to have the circles each represent one of the STEM components as depicted in Figure 1.6, which shows the STEM translation model (STL) as a variation of the LTM theory (Glancy & Moore, 2013). Figure 1.6 extends the basic concept with math at the center emphasizing the shared mathematical framework (or Venn intersection) across the STEM disciplines.

![Figure 1.6. The STEM translation model (with math at the center) as the combination of the individual disciplines along with the translations that connect them. Adapted from “Theoretical Foundations for Effective STEM Learning Environments,” by A. W. Glancy and T. J. Moore, 2013. In School of Engineering Education Working Papers. Paper 1 (p. 18). http://docs.lib.purdue.edu/enewp/1](image)

**Historical background.** The LTM theory traces its origins to the work of John Dewey c. 1899. He argued against “teaching subjects isolatedly from each other” (Dewey, 1966, p. 189). Dewey believed a siloed approach that partitioned or delineated related disciplines, diluted scholarly learning and detracted from a deeper understanding
Dienes (1960) extended Dewey’s idea by emphasizing the importance of collaborative work, interactive social learning, and connecting to the real world in the study of mathematics. Dienes claimed that “structure” reveals itself via the connections between different embodiments of a given concept or idea. He also defined mathematics in terms of actual structural relationships amongst concepts (Glancy & Moore, 2013).

The notion of collaborative work and interactive social learning gained much attention as catalysts for multidisciplinary pedagogy using structural relationships, thus lending credence to Dienes’ findings.

Sriraman and Lesh (2007) reinforced the importance of teamwork and structural relationships in STEM learning based on Dienes’ work. Lesh pioneered research to directly apply an integrated-environment approach to STEM learning based on Dienes’ work. The LTM’s structural relationship tenets of cross disciplinary problem solving, teamwork, learning related to personal experience, multiple manifestations, and representational fluency provide a firm theoretic basis for effective STEM pedagogy as evidenced by the multiple case studies described in Chapter 2.

Although the LTM theory is suitable in facilitating integrated and multidisciplinary STEM learning, complementary theories exist that reinforce the development of mathematical understanding. Pirie and Kieren (1994) developed a constructivist model of mathematical understanding defined as “a whole, dynamic, leveled but non-linear, transcendentally recursive process” (p. 166). Pirie and Kieren emphasized that, “mathematical understanding improves dynamically with back-and-forth movements between mathematical ideas” (p. 166). Lesh’s notion was that of a linear or unidirectional process of learning mathematics and constructing relationships
between multiple representations. The Pirie and Kieren (P&K) model proposed a nonlinear, recursive approach to mathematics understanding as a refinement of Lesh’s concept that was deemed consistent with the LTM integrated STEM learning framework.

Gülkılık, Hasan, and Yürük (2015) examined the efficacy of the P&K model applied to students working with representations of mathematical objects across a variety of scenarios that demonstrated the advantages of the back and forth thought processes. Whereas their focus was on nonlinear, recursive critical thinking in mathematics, the approach could be generalized across the STEM disciplines as they often share common mathematical threads, principles, and structural relationships. Notwithstanding, the LTM theory itself remains compelling because it provides a comprehensive framework for integrated, multidisciplinary learning readily applicable to the STEM domains. The P&K model can be used to augment or complement the LTM theory.

“STEM Curricula” (2017) offered a means of extending the basic LTM theory by applying the notion of an integrated curriculum to STEM learning for student engagement. A possible framework has been suggested that examines the continuum of curriculum integration across the STEM disciplines and that could be further extended to encompass subjects outside of STEM (Fogarty, 1991). The framework considered a stepwise, progressive approach to engage students as follows: (a) start with integration within single disciplines, (b) integrate across two or more disciplines, and (c) integrate within and across learners. Fogarty’s framework echoed in principle the tenets of the LTM theory, but addressed additional considerations namely,

- Defining learning goals and objectives—curricula that described the students’ acquired knowledge and skills demonstrable post-instruction;
• Developing purposeful themes and essential questions;
• Identifying a real-world problem to be solved;
• Purposeful inclusion of diverse content from other disciplines;
• Establishing purposeful partnerships—drawing on outside subject matter experts from academia and industry and from multiple content areas;
• Supporting critical thinking and problem-solving using the tenets found in the Next Generation Science Standards (NGSS)—an inquiry-based approach that draws on analysis and interpretation, constructivism, evidence-based dialogue, and communications (NGSS Lead States, 2013; NGSS, 2018); and
• Providing student feedback—measuring learning goals using performance-based assessments focused on acquired skills and applied knowledge.

Although certain limitations are implicit in the LTM theory, its framework enables the STEM gap causalities and the possible strategies for increasing STEM engagement to be examined within the context of integrated, multidisciplinary STEM pedagogy. An understanding of the theory and its limitations in terms of the STEM pedagogical process and practices helped to establish the purpose and direction of the research. The purpose of the research is further described next followed by the research questions that undergirded the study.

**Statement of Purpose**

The purpose of the research study was to fill the gap in our understanding of the factors that contributed to or detracted from STEM engagement/persistence for CNY high school seniors particularly during the transition period between 12th grade and upon entering higher education or the workforce. The vast body of research literature did not
specifically address the STEM gap issue for this demographic and timeframe. The goal of the study was to identify and investigate the root causes of STEM pedagogic gaps and determine if, how, and why integrated, interdisciplinary, and active learning interventions in recent years had successfully led to an increase in STEM engagement and persistence. The study drew on the perspectives of both high school seniors and STEM educators.

Recall that the research concerned itself with the relevant findings for a selected CNY high school case study in which the New York State Board of Regents *NYSED Next Generation Science Standards* (NGSS) were put into practice as the basis of an active STEM program (NGSS, 2018; NGSS Lead States, 2013; NYSED, 2019). The NGSS is derived from the “Framework K-12 Science Education” and the Common Core Standards (National Research Council, 2012a). Its importance in the overall purpose of the study is further discussed next.

**NGSS purpose.** The NGSS was intended to create new educational standards and guidelines for content enrichment and effective practice across multiple disciplines and grades centered on science and mathematics. According to Gillis (2013), a coalition of 26 states developed the NGSS in cooperation with the National Science Teachers Association, the American Association for the Advancement of Science, the National Research Council, and the non-profit organization Achieve. The NGSS provided a common standard for teaching and cultivating greater interest in science to encourage primary and secondary school students to pursue STEM majors in college. The NGSS-based curricula are conducive to case study research emphasizing critical thinking, logic processes, and primary or fundamental investigation.
The NGSS embodied three dimensions that are integrated in academic instruction: (a) core ideas, embodying specific content and subjects; (b) understanding the methods and practices of scientists and engineers, including emphases on scientific inquiry; and (c) concepts that cut across multiple disciplines. The NGSS was aligned with the Common Core State Standards and described academic “performance expectations” in science and engineering (Common Core, 2019; NGSS, 2018). Unfortunately, an apparent downside exists in the implementation of the Common Core State Standards. According to DiTullio (2018), the national policy rollout of the Common Core State Standards and Common Core Assessments has largely driven a barrage of “high-stakes” testing in U.S. schools. Jochim and McGuinn (2016) reported that the Common Core Assessments are the basis for teacher evaluations and in some cases, have influenced grant awards that could negatively impact school programs and detract from the long-term viability of the schools themselves. DiTullio concluded that the Common Core Assessments are yielding unintended and undesirable outcomes.

Berliner (2011) and DiTullio (2018) further cited the declining rates of U.S. student academic achievement following the implementation of the Common Core policy rollout per the National Assessment of Educational Programs (NAEP). Welner (2014) corroborated the declining trends in U.S. academic performance that were attributed to high-stakes testing. DiTullio claimed that the threat of ongoing high-stakes testing created a stressful environment which was counterproductive to developing academic proficiencies. The implications are potentially troublesome to STEM engagement and persistence. Referencing a study by Tokuhama-Espinosa (2011), DiTullio stated,
“humans learn best in a state of relaxed alertness, where the challenge is high, but the threat is low” (p. 10). DiTullio expanded on the theme as follows:

High-stakes testing creates a classroom environment where the challenge is high, but the threat is also high because there are potentially negative consequences for the schools, teachers, and students attached to test scores which do not meet the required proficiency levels. Another consequence of the Common Core assessments is the narrowing of state curricula. (p. 10)

In the present study, the STEM gap problem was initially examined through the lens of the NGSS and the Common Core State Standards. The NGSS highlights the fundamental knowledge and skills that students must possess to compete in a 21st century global economy. The study revealed important insights into the broader STEM persistence challenges and ways to overcome them that could influence leadership and organizational social change, and legislative and education policy changes that could spur STEM curriculum reforms in the future. The next section presents the relevant research questions on the STEM gap problem that align with the qualitative case study design.

Research Questions

The research questions examined STEM engagement and persistence using a qualitative case study research method for a selected high school and cocurricular sites. The questions were aimed at high school seniors participating in a STEM-type program and high school STEM educators. The research questions are as follows:

1. From the student’s perspective, how does participation in a STEM learning program stimulate or deter interest in pursuing a STEM major in college or as a career choice?
2. From the perspective of the educator, how do current STEM programs contribute to or detract from STEM persistence after high school, during college, and as a career choice?

3. From the standpoint of students and educators, why might STEM persistence or sustained STEM interest upon/after high school graduation be on the decline?

4. From the perspective of students and educators, how can interest in pursuing a STEM major in college or a STEM career be increased?

A qualitative, single case study design was deemed appropriate because it attempted to understand a context (a selected CNY high school) of the subject (STEM pedagogy) and its inherent dynamics (STEM learning environments), including human perspectives (those of STEM seniors and educators), and participants’ experiences (Creswell, 2007; Flick, 2014; Preskill & Russ-Eft, 2016). It is noted that the focus and findings of the single case study cannot be readily generalizable to other geographic contexts or populations. Nonetheless, a great deal of insight about the fundamental nature of the STEM gap problem was gained to identify similarities, convergent or divergent trends, and possible interventional strategies that could be studied and/or tested in a broader context. The alignment of the case study design, research questions that address the gaps, and the data collection methods is further discussed in Chapter 3. The significance of the study along these dimensions is discussed next.

Potential Significance of the Study

The research is significant because the current body of research reveals a gap in our understanding of the factors contributing to or detracting from STEM engagement
and persistence particularly during the critical transition period between 12th grade and upon entering college or the workforce. This is a crucial period in a student’s academic career in that he/she is faced with a life decision to either pursue a STEM major or a STEM profession or to focus instead on non-STEM pursuits. Although students are exposed to STEM during their pre-K-12 school years, an apparent discontinuity exists in how STEM interest is reinforced through pedagogy and practice by the time a student graduates from high school and upon entering college or the workforce. It is this critical period in a student’s academic career that demands closer attention to identify the factors influencing STEM engagement and persistence upon and after high school graduation.

An additional imperative lending to the significance of the study is the need for an in-depth exploration of the bridge between science and the fine arts for secondary in-service school practitioner preparedness and post-secondary administrator restructuring aimed at programs that exploit the power of integrated, interdisciplinary learning as a paradigm shift to close STEM engagement/persistence gaps. This restructuring points to potential pedagogical and organizational social change theories to be examined and applied in conjunction with pursuing new governmental and educational board policies to institute reforms in STEM pedagogy for increasing engagement and persistence.

The research is furthermore significant because high school STEM education is clearly lagging, and current STEM educational systems are not producing the desired outcomes. The research findings are anticipated to expose the pedagogic factors or challenges affecting STEM engagement and uncover ways of closing the STEM gap. High school students are the immediate demographic of interest because high school is the “last stop” in grooming true and meaningful interest in STEM and feeding the STEM
workforce pipeline. Nonetheless, the literature review drew on the relevant findings from secondary schools including middle school and undergraduate environments to gain insights into the broader STEM persistence challenges.

It is incumbent on educators and institutions now more than ever to assess the efficacy of current standards and determine what must be reevaluated to increase STEM engagement and persistence. It is also important for all stakeholders in the STEM pipeline (institutions, agencies, educators, students, and community leaders) to agree on the use of a reasonable set of terms and definitions to address the STEM gap problem in a consistent and meaningful way. The relevant terms and definitions are presented next.

Definitions of Terms

The following definitions were in effect with respect to the research questions posed.

Artificial Intelligence: The term artificial intelligence was coined by John McCarthy in the 1950s based fundamentally on the work of Alan Turing, a famed mathematician and cryptologist working for the Allied Forces during World War II (West, 2018). The term also refers to machines that can think autonomously to gather data, build knowledge, and assist human decision-making and tasking.

Career Aspirations: Refers to a career path that one aspires to pursue typically after secondary or post-secondary school education has been completed.

Curriculum Integration: Refers to “a knowledge view and curricular approach that consciously applies methodology and language from more than one discipline to examine a central theme, issue, problem, topic, or experience” (Jacobs, 1989, p. 8).
Integrated STEM: Refers to science, technology, engineering, and mathematics learning as an amalgam of the concepts, ideas, communicative skills, and higher-order thinking that links STEM disciplines together expounding the notion that STEM is more than merely the sum of its parts (Glancy & Moore, 2013).

Machine Learning: Refers to the intersection of the domains of artificial intelligence and data science. The term also refers to how machines are taught to mimic human decision-making using training data sets that are externally generated.

Multidisciplinary: Refers to combining several separate branches of learning or fields of expertise (multidisciplinary, interdisciplinary, cross disciplinary, and transdisciplinary are used interchangeably).

Spatial Skills: Defined as the reasoning that “concerns shapes, locations, paths, relations among entities and relations between entities and frames of reference” (Newcombe & Shipley, 2015, p. 179–180).

STEAM: Science, technology, engineering, arts, and mathematics.

STEM Engagement: Considers how two groups (educators and students) should interact and exploits methods to develop interest in science, technology, engineering, and mathematics through professional engagers, effective delivery schemes, community networks, institutional resources, previous learning activities or experiences, and forward-leaning thought (Bell, 2009; Merrill, 2009; “STEM Curricula,” 2017).

Translation: Refers to Lesh’s translation model theory and derivatives thereof.

The above terms and definitions are not all-inclusive and additional terms will be stated and defined in the discussions that follow. The terms above are “global” in that they are foundational to the full scope of the study. A chapter summary is given next.
Chapter Summary

This chapter established a foundation for the research study aimed at examining the efficacy of STEM pedagogy in Central New York State and the effects on long-term STEM engagement for senior-level high school students. A discussion of the research problem unveiled several disturbing trends that aggregately contribute to STEM disengagement. According to the International Activities Program National Center for Education Statistics (2015) and the Pew Research Center (2017), gaps in STEM engagement continue to widen. Gonzalez and Kuenzi (2012) reported declining trends in STEM persistence and increasing STEM pipeline leakage. The problem is traced to an apparent gap that exists in STEM engagement from the time of high school to when one enters college and later the workforce.

High school is considered the “last stop” in grooming true and meaningful interest in STEM and feeding the STEM workforce pipeline. The research focused on STEM engagement between high school and the post-secondary academic period to reveal ways of closing the STEM gaps. The research questions drew on the perspectives of high school seniors and adult educators and are consistent with the case study research methodology. The literature review which follows in Chapter 2 will delve in detail into the factors that contribute to STEM engagement, attrition, and the gap problem. The findings of the literature review in conjunction with the research questions were used to inform the detailed research methodology and study scope discussed later in Chapter 3. Chapter 4 will present the qualitative data analysis and findings followed by the implications and recommendations in Chapter 5.
Chapter 2: Review of the Literature

Introduction and Purpose

The topic of STEM and the STEM gap problem have been extensively documented in the literature for well over the past 20 years. The literature review examined several prominently cited factors that contribute to the STEM gap with emphasis on STEM pedagogy including academic curriculum, learning environment, and content delivery protocol. The review explored STEM gap findings from various geographic areas as extant studies and relevant published data for New York State secondary schools were limited or sparse. However, the present study ultimately confined itself to issues that reflect on or pertain to New York State high schools to the extent practical. The review was subdivided along three main dimensions accompanied by systematic reviews that cited representative, sample studies. The subdivisions included (a) the current state of STEM pedagogy and recent interventions, (b) applying integrated, interdisciplinary active STEM learning models, and (c) integrating non-STEM subjects illustrated via music and mathematics’ role in interdisciplinary learning.

The literature review drew on the perspectives of experienced researchers, educators, and subject matter experts who have proclaimed the need to improve STEM curricula by embracing a multidisciplinary learning model that breaks down the so-called “silos” within or between its subject areas. One such perspective is based on Lesh’s translation model (LTM), a theory which states that STEM engagement can be increased by understanding the synergy between the individual STEM disciplines through an active
learning process (Lesh & Harel, 2003). A logical extension of the theory would be to consider the synergy between STEM and non-STEM or arts-based disciplines on STEM engagement outcomes. The application and extension of the LTM will be further explored in this chapter.

Furthermore, due to the preponderance of empirical sources and peer-reviewed information on the present topic, the literature review confined itself to trends, observations, and findings in STEM education-based engagement for the dimensions of interest mainly since 2007; although, findings prior to 2007 are referenced at times to provide as complete of a picture as possible of the relevant STEM issues. Over 230 empirical, research-based, peer-reviewed primary sources, including reference books, descriptive articles, and online sources were cited throughout the dissertation. The studies were largely confined to those evaluated to be of medium-to-high quality based on the published qualitative or quantitative data. Certain low-to-medium quality studies were cited based on unique findings and were identified as such. Before launching into the relevant issues associated with STEM pedagogy and education protocols, a historical overview on STEM education is first provided, which underscores the study’s importance and lays the groundwork for the discussions that follow.

**STEM’s Origins—A Foundational Overview**

The underlying precepts of STEM have been in existence since the dawn of human civilization. The origins of STEM, as it is known today, can be traced throughout various points of recorded history. Some of the earliest examples of technology can be found in Stone Age carving tools, hunting implements, and ancient weapons fashioned over 200,000 years ago (indeed, early humans were also artists and artisans as evidenced
by cave art and jewelry made from seashells during the same era). Early African civilizations used rudimentary tools and weapons for hunting prey and for basic survival. Mesopotamian societies over 6,000 years ago engineered farming that led to the growth of agrarian communities and local commerce. Additionally, during that period, the early Greek, Egyptian, and Babylonian philosophers from the time of Aristotle, Plato, Ptolemy, and others began to question whether mathematical laws always existed and were discovered or were merely invented for human convenience.

The term “technology” derives from the Greek words techne (art and craft) and logos (word and speech); in modern terms, technology defines the advancements and changes that affect our environment (“Technology,” 2018). Other early examples of technology and engineering included the discovery of the wheel that led to rudimentary “vehicles” for transporting goods and people and for sport, to the architecture of the Egyptian pyramids and similar structures around the world, to the development of advanced weaponry, smelting practices, ancient medicine, and so on between the start of the Bronze Age (4000 BCE) and the late Middle Ages (roughly 1400 C.E.).

The Islamic Golden Age through the medieval times (c. 800 B.C.E. to 1250 C.E.) saw scientific achievements in astronomy, mathematics, medicine and pharmacology, alchemy and chemistry, botany, cartography, optics and rudimentary image projection devices, physics, and zoology (Dallal, 2010; El-Bizri, 2005). The ancient peoples of India discovered the Golden Ratio (also known as the Fibonacci sequence, codified mathematically by Leonardo Pisano Bonacci over 1,000 years later during the Middle Ages) and the Hindu-Arabic numbers (0, 1 – 9) we use today (Livio, 2003). Numerous other examples of the roles that the STEM subjects played can be cited throughout
history and around the world credited to the Sumerian, Phoenician, Persian, and Incan civilizations, among others. Indeed, the Arab cultures devised some of the first computers using the abacus and developed early numerological systems that were used in farming, astronomy, and celestial navigation that later made their way to the European continent and beyond.

During the Classical Age, the period between the 8th century B.C.E. and the 6th century C.E., the Greco-Roman civilizations flourished bringing forth mathematical discoveries and engineering marvels that stood the test of time. The Greek Parthenon and Roman aqueducts, water filtration systems, and networks of roads are some examples of soundly engineered structures and resource conveyance systems (Hornblower, 1983; Potter, 2006; Rhodes, 2006). The ancient Greeks were credited with discovering geometric and trigonometric first principles that are as applicable today as they were in their time.

A wealth of new discoveries in astronomy and mathematics followed from the late Middle Ages and throughout the periods of the Chinese Renaissance (960 – 1400 C.E.) and European Renaissance (14th to 17th centuries), that influenced societal development throughout parts of Eurasia, North Africa, and the Far East (Kuhn, 2009; Monfasani, 2016). The time between the Middle Ages and the early Renaissance periods saw the invention of gunpowder and ballistic weapons by the Chinese, followed by the Gutenberg printing press, and many other devices with counterparts found in today’s modern technology arsenal. The European Renaissance period witnessed the rebirth of the Classical Age that spurred innovations in science, engineering, and art by such luminaries as Kepler, Michelangelo, and da Vinci (Isaacson, 2017).
The Age of Enlightenment (Age of Reason) during the 17th and 18th centuries sparked a macro view concept of a new society and life philosophy that synthesized religion, art, science, classical philosophy, and politics that spread throughout Western Europe instigating progressive thinking and revolutionary developments in these subject areas (“Enlightenment,” 2018). Numerous discoveries and innovations arising from these periods further catalyzed engineering and technological advancements. The advancements included mechanical computing devices (Babbage’s “difference engine” and Ada Lovelace’s “thinking machine”)—progenitors of today’s modern computer invented during the Victorian period that helped launch the Industrial Age between 1760-1830 C.E. (Fuegi & Francis, 2003).

According to the Encyclopædia Britannica’s “Enlightenment” entry (2018), at the end of the Middle Ages, Humanism (the notion of humans as creative beings), the Renaissance, and the Protestant Reformation revived Classical Age culture and challenged the authority of Christianity, the Roman Catholic Church, and the Holy Roman Empire. Humanists questioned the traditional ways of thinking. Contemporaries of the time included Francis Bacon, Copernicus, and Galileo who pursued experimental science; whereas Descartes, Leibniz, and Sir Isaac Newton investigated new mathematical paradigms that survived the ages. Indeed, the new Enlightenment movement found its way to Colonial America during the 18th century. The movement soon led to the discovery of electricity and magnetism theory by Ampere and Lenz that was later mathematically codified by James Clerk Maxwell of Edinburgh, Scotland.

America’s interests in STEM education and studies began during the Colonial period (Salinger & Zuga, 2009, p. 4). Statesman Benjamin Franklin was infamous for his
many technical inventions including experiments in electricity. Similarly, Thomas Jefferson was intrigued by the science and art of agriculture and wine making. Historians also credited Jefferson with the inclusion of mathematics as a core subject to a bill he introduced in 1778 to help students “manage their affairs” (Urban & Wagoner, 2004).

Much later, advancements in transportation and weaponry were realized during the American Civil War.

The Morrill Act of 1862 and the National Education Association’s (NEA) Committee of Ten in 1893 were the forerunners of the contemporary STEM idea that began with the formal incorporation of science in the core educational curriculum (DeBoer, 1991; Reid, 2018; White, 2014). Assembly line tooling and factory production became mainstay processes immediately prior to, during, and after both World War I and the launch of the commercial automobile. According to Salinger and Zuga (2009), the U.S. federal government passed laws such as the Vocational Education Act of 1917 in support of career and technology education. Thomas Edison’s electric light bulb emerged along with the dawn of the telephone, overseas radio communications, Einstein’s general theory of relativity and special theory of relativity, quantum mechanics, automobile, airplane, refrigerator, television, polio vaccine, and so on which collectively ushered in the modern era of science and technology (S&T) during the early-mid 20th century.

World War II spurred further advancements in telecommunications and radars, modern transportation, computers, and weapon systems based on vacuum tube technologies. The early 1950s through 1970s saw the emergence of transistors, integrated circuits, modern computers, the launch of Sputnik, the race to space, and the
early age of the Internet all spurred on by the Cold War (White, 2014). Research and development (R&D) in these areas was echoed at the time by the newly formed National Aeronautics and Space Administration (NASA), the Defense Advanced Research Projects Agency (DARPA), and the National Science Foundation (NSF), and later by myriad commercial companies in California’s Silicon Valley in support of federal research programs for technology advancement.

The early success of NASA’s space program during the 1960s depended on new rocketry, computer, navigation, and sensor technologies of the time culminating in the first moon landing on July 20, 1969 (where the computers at that time were significantly less powerful than today’s smart phones). Eagleman (2015, p. 179) referenced the work of Gordon Moore of Intel fame who in 1965 postulated “Moore’s Law,” which forecasted the exponentially accelerating pace of technological advancement in the modern age based on an approximate every 2-year cycle. Eagleman further conjectured that at the predicted rate of advancement, 20,000 years’ worth of technological progress will be realized within the next 100 years.

Indeed, NASA has been largely responsible for many STEM education programs and initiatives today that have contributed to the rapid rise in technological advancements. Early gaming products grew out of the Silicon Valley during the mid-late 1970s through the 1980s that leveraged computing technologies originally designed for space exploration and defense purposes. The developments led to new, high-technologies companies being formed such as Intel, Microsoft, and Apple. The growth then led to a major surge in commercial technologies and applications such as the cell
phone and personal computer (PC). Early efforts at exploiting alternative power
generation technology and engineering (solar and wind) also began during the 1970s.

The first cell phone became commercially available in limited use in 1983 and
between 1995 and 1999, the growth in cell phone and personal computer users exploded
along with the emergence of the modern Internet, ushering in the Information Age.
Interest in genetic engineering grew during this period. Then, in 2007 the first Apple
iPhone was released and the age of STEM as we know it today began. The iPhone and
comparable smart devices of the time combined the phone, Internet, digital computer,
personal scheduler, and audio/camera recording capabilities into a single, convenient
package with an ergonomic look and feel. The iPhone was considered a game-changing,
disruptive innovation that to this day incites new product development and ongoing
technological disruption in information technology that began during the 1980s.

The push today is toward nanotechnology and advanced wireless connectivity
coupled with artificial intelligence (AI) and machine learning implemented on
autonomous platforms and systems (hand-held devices, aerial drones, robotic systems,
connected vehicles, satellites, and so on). The technologies are enabling the Internet of
Things (IoT) to pave the way for smart cities of the future and to enable flat earth global
commerce (Friedman, 2007; Miller, 2015). Today, the space age is experiencing a
renaissance with plans to revisit the moon and colonizing the planet Mars. The point here
is that STEM in its various component manifestations throughout world history and
geography played a crucial role in how great societies and nations emerge, grow, survive,
and thrive over time. Indeed, this historical tour of STEM as it is known today is far
from complete and provides only a partial glimpse at best; however, the impact of STEM
significantly contributes to the rise and fall of great nations from the perspectives of economics, politics, and military might.

Indeed, the U.S. government recognized the need to continuously be on the forefront of scientific advancement and achievement and to maintain its technical competence if America is to maintain its status as a global superpower and assure its worldwide competitive advantage politically, economically, and militarily. A thriving economy and strong military are directly proportional to the levels of scientific and technological achievements. Kennedy (1987) posited the following theory:

The relative strengths of the leading nations in world affairs never remain constant, principally because of the uneven rate of growth among different societies and of the technological and organizational breakthroughs which bring a greater advantage to one society than to another. (p. xv)

Kennedy (1987) further said in the context of so-called statecrafts,

The triumph of any one Great Power in this period, or the collapse of another, has usually been the consequence of lengthy fighting by its armed forces; but it has also been the consequences of the more or less efficient utilization of the state’s productive economic resources in wartime, and, further in the background, of the way in which that state’s economy had been rising or falling, relative to the other leading nations, in the decades preceding the actual conflict. For that reason, how a Great Power’s position steadily alters in peacetime, is as important to this study as how it fights in wartime. (p. xv).

Notwithstanding, America’s status as a global economic and technological leader has been challenged in recent years. One of the challenges facing the US is the erosion of
STEM literacy. The decline in STEM persistence (the lack of sustained academic and career pursuits in STEM) by American students, coupled with poor STEM academic performance compared to their international counterparts, is at the heart of the issue. Of further concern, from the perspective of some Americans, is the steady influx of foreign nationals over the past 20 years seeking STEM career opportunities in the US, and the perceived threat to American job placements in STEM capacities, coupled with the belief that the same foreign nationals could return to their home country after a time. This has often been called the “brain-drain” effect. Consider the perspectives on STEM over the past 20 years and how STEM has evolved since 2007 to address the problem, including reforms that leading advocates of STEM pedagogy in schools and professional organizations across the nation have explored.

**Evolution of the STEM concept.** Springer and Stanne (1999) referenced several landmark studies conducted in the 1980s and early-mid 1990s that identified the need to shore up U.S. education in science and mathematics in what was at the time called SMET (Science, Mathematics, Engineering, and Technology). According to McComas (2014), Sanders (2009), and White (2014), SMET—a precursor of STEM—was coined and initiated by the NSF in the early 1990s (Judith A. Ramaley of the NSF was later credited for recoining it “STEM,” which became the acronym of choice c. 2005). The initiative was intended to help American students develop critical thinking and creative problem-solving skills to ultimately become more marketable in the U.S. labor force.

By 2008, the STEM acronym became part of the educational lexicon and continues to be recognized internationally (Loewus, 2015). The landmark studies cited by Springer and Stanne pointed to the need for “instructional innovations” via a paradigm...
shift that de-emphasized the teaching aspect and focused more strongly on learning “through active, collaborative, small study-group work inside and outside the classroom,” setting into motion a series of innovations and reforms (American Association for the Advancement of Science, 1989, 1990; National Commission on Excellence in Education, 1983; National Research Council, 1995, 1996; National Science Foundation, 1996; National Science Foundation & U.S. Department of Education, 1980). According to Loewus, since c. 1985 educators treated the individual STEM disciplines in relative isolation. However, 15 years later (just prior to 2001) educators began to “link” the individual disciplines, thus establishing the foundation for the new STEM movement; yet experts only loosely related the disciplines to each other until the 2003-2005 timeframe. The efforts to interrelate the individual STEM disciplines more tightly as the basis of today’s STEM education agenda and future directions are reviewed next.

**Contemporary STEM education and early attempts at reform.** Gonzalez and Kuenzi, (2012), Reed (2018), Sanders (2009), and “STEM Curricula” (2017) underscored the increased focus by U.S. government agencies and academia in proliferating STEM education over the past 20-25 years. As evidence of the growing emphasis on STEM, “STEM Curricula” cited the emergence of such organizations and programs as the Education Commission of the States, National Academies of Engineering, Tapping America’s Progress, STEM Education Coalition, International Technology and Engineering Educators Association, National Science Teachers Association, National Research Council, and others. However, each source pointed to certain deficiencies in modern STEM education.
From a historical perspective, White (2014) highlighted that preeminence of science and mathematics in the modern STEM curriculum, noting that the technology and engineering fields were the most underrepresented and underfunded in K-12 education. Reed (2018) claimed that STEM continued to be taught in large part as siloed disciplines, ignoring the reality of today’s integrated product-team-oriented environments while overstressing standardized testing—an approach that can stifle STEM engagement. He further posited that the “T” in STEM had not been clearly defined, the “E” not thoroughly exploited in educational curricula, and “arithmophobia” not having received the proper attention in our attempts to understand STEM engagement; although, Reed believed that the “S” had been well-defined in pre-K-12 education. He further claimed that the “M” enabled crossover skills to be developed through the interdisciplinary connections among the STEM disciplines and subfields—an aspect often overlooked and widely validated by the Next Generation Science Standards (NGSS) and Standards for Technological Literacy (STL), which established a paradigm shift in STEM education in recent years (NGSS, 2018; NGSS Lead States, 2013; ITEEA, 2007). The NGSS has been put into practice by most states in the US and the STL was funded by the NSF and NASA and endorsed by the National Academy of Engineering, thus attesting to the standards’ credibility and utility in attempting to reinforce meaningful STEM education.

Reed (2018) identified a disconnection between the proliferation of makerspaces and technical competitions (such as robotics tournaments) and the lack of more in-depth exposure to technology and iterative design courses including sociocultural exposure for students. Petrina (2007) described the “technoenthusiast” mindset often associated with “makerspace mania” that undermines the rigorous study of technology by diluting it with
an over-infusion of activities across a broad range of school programs and cocurricular activities. Petrina and Reed suggest that the technology education discipline in the US is shrinking and this may be due to declining budgets, lack of trained educators and teacher education programs, and fewer regular courses. Per Reed, these factors in aggregate may be significantly contributing to today’s STEM gap.

Next, U.S. national demographics on underserved and impoverished rural communities revealed yet another disturbing fact contributing to the STEM gap. According to Yaffe (2018a), nearly 20 percent of public-school students in the US were enrolled in rural school districts that were severely resource limited. Yaffe cited the shortage of qualified STEM teachers as the most critical factor, further stating that the quality of STEM education varied significantly between urban and rural communities due to a lack of funding and hampered resources, resulting in inequity and unequal opportunity for some students, teachers, and school districts.

Yaffe (2018b) claimed that cultural factors have challenged efforts by rural school districts to encourage underserved families to embrace STEM learning and to dispel any notion of such learning as reserved to affluent or privileged groups. Ravitch (2010, p. 285) asserted that schools alone cannot solve the problems of poverty and inequity in education. Ravitch suggests that the overemphasis on passing scripted state tests and not preparing students to deal with the realities of failure only exacerbate matters.

Once again, the obvious strategy tried by many has been to exploit technology to the fullest to “energize” the STEM curriculum and engage students’ interests. Admittedly, technology can compensate for resource shortages including the dearth of STEM teachers in rural districts via online and telecommunications tools. However,
Ravitch (2010, p. 285) offered more generally, that schools should concentrate foremost on teaching people academic skills that can be put into practical use to improve the “social condition.” Notwithstanding, STEM holds promise for reviving underserved communities and providing for expanded opportunities for students, educators, and school districts alike.

To effectively address the gaps, one must thoughtfully examine the past 20 or so years of STEM history, developments, and milestone achievements. DeBoer (1991) cited multiple examples of STEM-type education reforms of core school curricula in the US as far back as 75 years ago that were deemed marginally successful at best and required alternatives to be considered, ever since such reforms were first instituted in 1893. Ravitch (2010, p. 5) cautioned that general educational reform was most effective when put into practice incrementally and progressively, rather than in monumental “leaps and bounds” that may be driven by special interests or a misguided national agenda. Reed (2018) later asserted that any new approach for improving student engagement in STEM should focus on how K-12 teachers were educated, cultured, and supported throughout their careers to make them effective, inspirational STEM leaders.

Ravitch (2010, p. 284) insisted that quality education was dependent on the close interaction or engagement level between the educator and an inquisitive student; furthermore, education and its delivery should reflect contemporary society’s values and world events at the time, and to make learning “lively.” The recommendations by Ravitch and Reed (2018) were consistent with the earlier findings of a prior federal study that examined learning patterns and brain development influenced by positive environmental factors associated with classroom teaching and a balance of cocurricular

Numerous other studies by federal and educational organizations have previously identified the need for reforms focused on implementing newer science standards that amplify the importance of connecting the STEM disciplines and modifying how STEM is taught both from the perspectives of K-12 educators and students (National Research Council, 2005a; National Research Council, 2005b; National Research Council, 2009; National Research Council, 2012a; National Research Council, 2012b; National Science Board, 2010; National Science Teachers Association, 2019; U.S. Department of Education, 2011). The NGSS addressed many of the concerns in STEM education and reform that were raised by the studies. In particular, the standards stressed the integration or linkage of the teaching practices of scientists and engineers with the effective delivery of content in the classroom.

The innovative ways of integrating and delivering STEM curricula have led to a major shift away from the traditional STEM pedagogical paradigm in which the subjects are taught in relative isolation and absent of real world “practice” and interactivity (NGSS, 2018). Earlier efforts dating back to c. 2007 have paved the way for interventions and reforms to overcome the deficiencies in traditional STEM learning and establish a “new age” of STEM pedagogy built upon an integrated, multidisciplinary paradigm. A further assessment of the state of STEM pedagogy is provided next offering glimpses into ways of closing the STEM learning gaps that have been tried and tested including the potential pitfalls.
STEM Pedagogy and Learning Protocols

STEM learning has traditionally been a siloed, didactic process in which the individual STEM subjects are taught in isolation largely using lecture-based instruction (Wu-Rorrer, 2017). The literature review will not belabor the apparent issues or inherent limitations of siloed STEM learning except to note that the practice persists to a large extent and is at the core of the research problem. The point of departure then will be to gain an understanding of the nature of the limitations, interventions, and studies that can inform ongoing research to develop and implement best practices. The empirical studies addressed the limitations in STEM learning and identified possible interventions or reforms such as the application of the LTM theory to enhance STEM engagement.

Consider the intervention tested by Lesh and Doerr (2003) in which they posed a “Big Foot” challenge problem using the LTM theory and where teachers asked students to develop a mathematical description of an exact proportional relationship between a person’s height and shoe size. The exercise leveraged the students’ experiences and knowledge of physical-spatial dimensions and representational structures to augment their conceptual understanding of practical solutions using mathematics drawn from the real world, including physics principles governing force and motion. The students and teachers found that connecting learning to the real world (and experiences) was essential in abstracting mathematical structure and applying it in a practical way to successfully complete the task of developing a useful height-to-shoe-size relationship. The “Big Foot” challenge is one of several examples that demonstrates the efficacy of the LTM theory in practice.
Glancy and Moore (2013) cited an example of a group project where the tenets of the LTM theory were used to design a windmill. Students in a group were asked to collaborate with each other to diagram the plans for a windmill with specific blade configurations and for varying wind speeds drawing on their skills from multiple disciplines. The project tested the students’ resolve in conceptualizing, communicating, and manifesting concepts and representations based on their group experience as they felt the varying wind strengths.

The LTM theory leveraged STEM-based symbolic manipulation (mathematical descriptions) related to conceptual understanding (the relationship of wind force to blade size and how wind affects blade rotation) and experience (physically manipulating blade scale models) to successfully complete the task. Once the students removed themselves from the group to research isolated mathematical or scientific principles, the more the task became one of a siloed research project with less understanding of the “bigger picture” goals and where non-STEM considerations were completely overlooked such as considering aesthetically pleasing designs, ease of repair, and so on.

Although Lesh and Doerr (2003) focused on STEM in their research and case studies, the application of the LTM theory is not strictly limited to the domains of STEM. Theoretically, it could be applied to both STEM and/or non-STEM domains. Dewey (1938) inspired the origins of the LTM theory and hypothesized that any set or subset of multidisciplinary domains could be shown to be highly interconnected, albeit on the surface they appear as relatively isolated domains. Dienes (1960) focused on mathematics and structural relationships to tangible, real-world artifacts and experiences. He alluded to the relevance of mathematics across virtually any discipline of study.
Hence, the LTM framework can conceivably serve as a model for STEAM learning that includes non-STEM or arts and humanities disciplines. The literature review did not uncover any direct evidence of the LTM theory applied to combined STEM and non-STEM disciplines for increasing STEM engagement or for any other purpose, leading potentially to new hypotheses and areas of study.

One such hypothesis might suggest that applying the LTM theory to STEM education inclusive of non-STEM subjects could boost STEM engagement and improve STEM outcomes. For example, direct relationships can be made between mathematics and musical composition or between science and the art of communication. Many disciplines share a common mathematical framework for describing functional patterns or mutual behavioral characteristics. Multiple examples can be cited of interleaving science and art disciplines as the basis for a STEAM pedagogical model. Consider next the example of science communication to illustrate the point.

Recall that STEM engagement fundamentally considers how two groups should interact and exploits methods for effective science communication to generate interest in STEM subjects (Bell, 2009). The art of science communication, which derives in part from improvisational and performance art, applies LTM theory in a mixed STEM and non-STEM scenario to eliminate complex technical jargon; reduce a message to its essence or simplest form; and add a colloquial and enjoyable element to content delivery. The scenario represents a method for sparking inquiry, curiosity, creativity, and stimulating dialogue using multidisciplinary STEM with arts learning that could be used to increase STEM engagement.
However, the opposite effect should also be considered. The dissertation will reexamine the LTM theory’s role in such applications and investigate whether including non-STEM subjects could reinforce or possibly dilute STEM affinity or detract from STEM learning capacity. The following background discussions further provide a foundation for enhancing our understanding of the models, strategies, protocols, and interventions that have been tried and tested in STEM pedagogical environments.

**Background on Models, Interventions, and Collaboration Strategies**

The literature review identified two main categories of interventions or strategies that can play important roles in STEM learning and engagement. The categories include model-based interventions and collaborative-social interaction strategies. Both categories share certain characteristics and have common goals but emphasize different aspects or manifestations in the context of STEM learning and engagement. Both categories are further described next and add to a foundational understanding of the STEM gap problem that will be subsequently referenced in the literature review and analysis.

**Model-based interventions.** Generally, the interventions applied to traditional STEM pedagogy draw on a variety of learning protocols or methods. The protocol types include inquiry-based learning (IBL); project-based learning (PBL); context-based learning (CBL); scenario-based learning (SBL); goal-oriented learning (GOL); and active interdisciplinary learning. Other extant approaches represent hybrids or variants of the types listed. The review will concentrate on the protocols used most frequently in STEM pedagogy albeit, not ubiquitously. The most popular or widely used protocols include the PBL, SBL, IBL, and active interdisciplinary variety where the latter two are of special interest.
The protocols identified share several common characteristics. Mainly, they all build upon the themes of small-group activity; practical, real-world problem solving; significant teacher-student interaction; trust in educators; inspirational teachers who motivate students; educators who can influence positive change in the classroom; self-efficacy and confidence; and academic achievement. Collaboration and interactive social strategies play an important role in STEM learning and engagement, especially in small-group activity sessions, and is further discussed next.

**Collaborative-social interaction strategies.** The notion of collaborative work and interactive social learning gained much attention as catalysts for interdisciplinary pedagogy using structural relationships. The approach is the basis for an integrated, interdisciplinary active STEM learning strategy that treats mathematics as a “glue” binding and interrelating the disciplines for highly purposeful engagement. The approach exploits a method called *scaffolding*, which will be discussed later and refers to a framework for an interactive, immersive intervention by teachers to facilitate students’ problem-solving skills development and enable interdisciplinary learning in a progressive or iterative manner. A multitude of empirical studies are presented next that address the various touchpoints in STEM pedagogy and that bear the common themes above plus other features of interest starting with the impact of academic, collaborative group environments on STEM engagement.

**Empirical Studies on STEM Pedagogy and Engagement**

Springer and Stanne (1999), in a seminal meta-analysis on STEM education since 1980 conducted for the National Science Foundation (NSF), showed that small-group learning (between two and ten students) in the classroom was found to enable effective
STEM learning. Their study supported the idea of implementing ubiquitous small group learning in secondary and higher education institutions and was designed to inform institutional policy and practice. Springer and Stanne focused on the learning outcomes associated with academic achievement, persistence, and student attitudes (self-esteem, motivation, and STEM learning potential). They accounted for conditional effects of small-group learning, namely (a) potential sources of bias in effect sizes from the studies screened, (b) differences among various student groups (STEM versus non-STEM majors, grade, gender, race, and underrepresentation), (c) whether different small-group learning patterns (duration of group activity) were related to the outcome measures, and (d) assessing outcomes across the dimensions of self-esteem, motivation, and attitude.

The meta-analysis by Springer and Stanne (1999) was considered of high-quality based on the specified inclusion criteria and effects size metrics. Five inclusion criteria were applied in selecting the studies. The selected studies had to (a) contain data on STEM undergraduates at accredited postsecondary North American institutions, (b) focus on small-group work within or outside of the classroom, (c) be conducted in a realistic classroom setting and not under laboratory-controlled conditions, (d) be published in 1980 or later, and (e) contain sufficient statistical information to estimate effect sizes. Cohen $d$-indices and chi-squared regression statistics were calculated based on control and experimental groups in natural classroom settings lending to the study’s credibility.

Springer and Stanne identified a total of 383 relevant small group learning reports from 1980 or later, drawing on 39 critical studies that met all the desired inclusion criteria. Using independent samples, relevant studies, and findings, they found that small group learning had a significant benefit on STEM learning achievement ($d = 0.51$),
persistence \((d = 0.46)\), and attitude \((d = 0.55)\). Overall greater performances were measured for students in group settings compared to students who received traditional instruction absent of collaborative grouping, regardless of effects size weighting that accounted for biases or group differences. Brown (2012) corroborated Springer and Stanne’s findings on the benefits of small group learning and underscored the need to inject real-world problem-solving experiences in STEM education.

Brown (2012) canvassed the STEM education research base to determine emerging trends that could lend to an understanding of the relevant, overarching research questions and findings pertinent to STEM engagement. The study’s research questions centered on the scope of research being conducted, by whom, and the participants in the research. Brown concentrated on primary sources drawn from eight major journal articles that addressed K-12 up through university-level STEM pedagogy. He examined over 1,100 articles published between January 1, 2007 and October 1, 2010 to sift out dominant themes using a qualitative, descriptive content analysis approach. Brown’s study is of high quality due to the vast number of articles identified. Overwhelmingly, the sources cited by Brown focused significantly on integrative STEM education.

Brown (2012) reported that most of the articles addressed at least two fields of study related to STEM learning namely, content diversity and delivery environment or mechanism. First, his findings provided an early indication of the changing viewpoint on STEM as being more than a collection of separate or stand-alone disciplines. Nearly all the STEM articles identified in the study were concerned with how to exploit the integrated, interdisciplinary nature of STEM. Second, the findings addressed topics on practical STEM pedagogy highlighting the importance of small group tasks to solve real-

Winston and Zunker (2010) proposed a model to predict blood alcohol content using mathematical and scientific modeling techniques to augment the use of computer and measurement technologies. The project successfully demonstrated the marriage of science, technology, engineering, and math in a single, small-group activity designed around a real-world problem. Their study revealed an emerging trend in STEM as an integrated, interdisciplinary concept applied to practical applications and small group activities. Winston and Zunker supported the findings of Brown (2012) and Springer and Stanne (1999), thus reaffirming the utility of active, small-group STEM learning via an integrated, interdisciplinary approach. Several more recent studies revealed other factors underlying STEM engagement and persistence.

Jackson, Charleston, and Gilbert (2014) conducted a qualitative SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis to assess the efficacy of secondary and higher education STEM engagement practices. They identified the emergent themes of past learning experience, teacher competency, STEM subjects taken, and motivational factors. Jackson et al. cited the main predictors for STEM disengagement as poor teacher quality, lack of motivation in the classroom, and math and science gaps due to inadequate preparation in high school. The former two predictors resonated with the findings of Brown (2012) and Springer and Stanne (1999) on the importance of a nurturing STEM learning environment that actively engages students, fosters trust and openness, is challenging, and inspires creative problem solving.
The study by Jackson et al. (2014) was limited to data collected in Wisconsin’s M7 counties which were STEM-rich zones. External validity was uncertain, and their study was of moderate quality based on the sample size and study design and control, although their findings were corroborated in part by other studies. However, unlike the studies of Brown (2012) and Springer and Stanne (1999), Jackson et al. further highlighted the importance of educator readiness, positive educator attitude, and the ability to inspire STEM interest.

A quantitative study by Sankar and Raju (2011) hypothesized the relationship between mitigating STEM learning barriers and positive STEM outcomes across several dimensions accounting for educator factors. The dimensions included the impact on higher-order cognitive ability, enhancing self-efficacy, and improving team learning and critical thinking skills in math, science, and engineering via visual, project-based tasks. They tested the hypothesis on learning outcomes by considering teacher-student interactions, group activity, and visual learning. An augmented Biggs and Moore 3P (presage, process, product) model that included pedagogy was used to test the hypothesis on the learning outcomes of 86 participants at two universities using the Index of Learning Styles (ILS) as the measurement instrument along with pre- and post-questionnaires and student grades.

Sankar and Raju (2011) found that students had an overwhelming desire for visual-multimedia and small-group PBL collaboration to enable creative problem-solving. Linear regression analyses showed that the students’ prior grade point average (GPA) marks dominated all other variables in predicting class performance followed by self-efficacy and perceived higher-order skills holding constant all other control
variables. The research did not report results for multimedia or multimodality cases that were omitted, thus lowering the study’s quality to low-moderate at best.

Li, Huang, Jiang, and Chang (2016) performed a quantitative study that addressed STEM engagement and skills reinforcement via a tactile modality using Lego bricks. Li et al. showed how using a goal-oriented, design-based pedagogy can stimulate creativity in the areas of science, math, and engineering design; facilitate increased teacher-student interactions; and build trust in educators’ STEM pedagogical skills. However, the small sample size, limited pedagogy testing methods, and single institution study called into question the external validity of their results (with effect size \( r \) values between 0.013 and 0.4—measuring performance improvements in STEM learning and problem-solving skills, respectively) and to conclude a low-moderate quality study. Nonetheless, the aggregate findings of Li et al. and Sankar and Raju (2011) highlighted the importance of (a) qualified educators who can effectively engage students; (b) solid math and science foundations; (c) design-based pedagogy; and (d) multimedia, multimodal aids operationalized within a PBL framework.

DiTullio (2018) raised the importance of multimodal learning strategies that “engage the entire physiology” and provide for orchestrated immersion. Research by Akyurek and Afacan (2013), Duman, (2010), Gabriel (1999), and Mullender-Wijnsma et al. (2015) corroborated the effectiveness of visual aids, kinesiology, olfactory sense, interactive collaboration, interpersonal communications, and music in stimulating general learning. DiTullio also pointed out that per Jensen (2008a), scent or smell is an underutilized modality in the learning environment that can be used to enhance mental awareness or induce a calming effect that can make one more receptive to learning.
Ernst, Williams, Clark, Kelly, and Sutton (2018) quantitatively analyzed the degrees of autonomy, control, or influence that STEM educators have on school policy. They addressed the STEM teacher’s level of satisfaction and willingness to invest in creative and rewarding STEM activities. Educator autonomy, control, and influence were shown to positively associate with empowerment, educator retention, and motivational learning for STEM persistence. Ernst et al. found that technology educators possessed the highest levels of control and influence in the classroom and on school policy because of their active and visible efforts to promote technology budgets and expand the use of technology devices in their schools.

Ernst et al. (2018) concluded that technology educators were most effective in motivating STEM interest because they can exert more control in the classroom, influence school policy in their favor, and implement curricula that stimulates technology interests. The study by Ernst et al. is of high-quality based on hypothesis testing (independent sample t-tests), the highest positive predictive value (PPV) of the study (with SMD values approaching 1), and strong sampling lending confidence in the study’s external validity. Their findings agreed with those of Jackson, Charleston, and Gilbert (2014) on the importance of positive educator attitude in motivating and engaging STEM students and in seeking institutional reforms.

Next, a qualitative study by Kezar and Gehrke (2017) investigated scaled and sustained STEM reform. The top three reform foci were disciplinary, institutional, and sector. On the disciplinary focus front, professional societies would be consulted to help shape or alter the teaching standards across the STEM fields emphasizing textbook development and instructional content delivery. On the institutional front, the importance
of socializing new practices across STEM departments for institution-wide reform was highlighted. The sector focus area targeted small liberal arts colleges to institute STEM reforms that promoted interdisciplinary learning.

Consistent with the study by Ernst et al. (2018), Kezar and Gehrke (2017) suggest that institutions are well positioned to establish the policies and rewards that resonate with faculty who in turn, can help spur reform. Their institution-based findings included utilizing consultancies, active outreach, sponsoring or encouraging curriculum-based projects, and curating leadership development. Kezar and Gehrke’s study was considered a moderate-quality study because of the modest sample size (non-randomized), the qualitative design and control method used, and moderate external validity based on the data sampling across four diverse community of practice (COP) groups. Yet, the study lent credence to the issues and values that cut across other STEM persistence studies, namely those concerned with how educators can stimulate students’ involvement and investment of time and effort for STEM group project engagement.

In a National Science Foundation (NSF) qualitative study, Stage and Kinzie (2009) identified six dimensions of effective STEM learning reform for increased STEM persistence and student satisfaction. The dimensions included changes in pedagogy, incorporating active (hands-on) learning and peer teaching, use of authentic or real-world contexts, collaboration (social, small group learning), and interdisciplinary connections. The findings were consonant with those of Brown (2012), Kezar and Gehrke (2017), and Springer and Stanne (1999). One of the recommended changes in teaching and learning highlighted increased faculty–student interactions, which had two important implications.
The first implication from the Stage and Kinzie (2009) study was that reducing “faculty authority” in the classroom should facilitate a more balanced, open, and bidirectional inquiry between teachers and students. Reducing the barrier would enable improved student-teacher interactions where STEM theories and practices could be more readily applied to solve real-world problems in an open, project-based setting. The second implication was consistent with the study by Kezar and Gehrke (2017) that suggests institutions should establish the policies and rewards that motivate faculty to spearhead reforms that adapt STEM learning to meet the students’ diverse needs and expectations. According to the independent studies by Kezar and Gehrke and by Stage and Kinzie, implementing such policies would enable faculty to have greater autonomy and control over developing and delivering novel, impactful STEM curricula.

The study by Stage and Kinzie (2009) was deemed of moderate quality due to the relatively modest sample size, although the design and control method along with the use of reliable, diverse data from prior NSF studies lent credibility to the findings. Their study had moderate external validity based on the data sampling across three widely separated geographic areas of the US. The tenets embodied in the Stage and Kinzie study were rooted in strategies that employ a technology enhanced PBL approach.

The NSF supported a wealth of studies to expand the understanding of best practices and contexts for motivating K-12 students’ interests in STEM via the use of technology in PBL settings. A qualitative, content-review-based study by Connors-Kellgren, Parker, Blustein, and Barnett (2016) focused on the merits of curriculum- and project-based learning built upon the NSF’s Innovative Technology Experiences for Students and Teachers (ITEST) Program. The ITEST employed a combination of
technology-enhanced STEM education, project-based learning and design, and teacher-student engagement strategies to rapidly cultivate STEM interest. Their study was deemed to be of moderately high quality.

Connors-Kellgren et al. (2016) showed that students’ STEM engagement increased by coupling technology-enhanced STEM curricula with STEM career development projects that included design activities. The study led to emerging theoretical models that continue to be developed, tested, and validated to elucidate the steps involved in youth STEM career development and to nurture one’s willingness to invest their time and effort in STEM pursuits. Some of the theories examined the degree to which a student wants to be emotionally invested in STEM, leading to another consideration—a sense of belonging to a community of practitioners or fellow learners.

Wilson et al. (2015) quantitatively examined the links between belonging and emotional investment by U.S. STEM undergraduates across five geographically- and culturally-diverse institutions. Using a survey instrument and a non-randomized, criterion-based sample size of 1,507 participants (497 females, 1,010 males), they measured belonging in the STEM classroom environment. The sample data were obtained from STEM courses or via STEM activity groups over a 2-year period. Multiple regression analyses showed a significant, positive intercorrelation from moderate (0.25–0.40) to strong (0.50–0.75) between the belonging and engagement measures for each of the schools that participated in the study. The study confirmed the importance of cultivating a sense of belonging and nurturing self-efficacy in STEM learning. It also complemented the study by Connors-Kellgren et al. (2016) on the factors related to youth STEM career development and investment in STEM pursuits.
The study by Wilson et al. (2015) also determined that the sense of class belonging in a STEM context correlated with behavioral and emotional engagement. The finding was further linked to students’ behavioral or emotional actions or their level of active engagement in the classroom, providing indicators of an association between student motivation and academic progress. The finding reinforced those independently arrived at by Connors-Kellgren et al. (2016) and Ernst et al. (2018) regarding personal investment. Wilson et al. showed that self-efficacy and class belonging significantly impacted STEM coursework engagement across the five schools. The study was deemed of high quality underscoring the importance of students’ perceptions of belonging and the need to foster productive teacher-student classroom engagement. Comparable findings and observations were found with the use of scenario-based learning (SBL).

SBL is gradually finding its way into the STEM classroom; however, limited examples of integrating SBL into STEM curricula were found in the literature. A qualitative study by Proudfoot and Kebritchi (2017) measured participants’ perceptions on the efficacy of STEM learning in a scenario-based, mobile eLearning laboratory setting. In the study, semi-structured interviews were conducted for 12 elementary school educators from the U.S. Southeast who were selected from a population of 5,213 educators through a non-probabilistic, criterion sampling procedure. The goal of the study was to assess the participants’ perceptions of the mobile eLearning STEM lab format on the students’ levels of STEM engagement and self-efficacy.

The study by Proudfoot and Kebritchi (2017) suggests that SBL coupled with an eLearning approach increased learner engagement. The finding was highly resonant with the study by Wilson et al. (2015) for a different learning protocol. The authors inferred
from the content analysis that educators perceived a positive influence in STEM and non-STEM learning on students when SBL was integrated into the lesson plans. The SBL opportunity provided for a hands-on experience facilitating active ways to explore STEM. However, in terms of qualitative research the study was considered weak to moderate at best as it could not be corroborated by other studies concerned with SBL in STEM engagement, and the sampling method and sample size were limited. The results could not be readily generalized to broader populations. Notwithstanding, Proudfoot and Kebritchi’s study raised awareness of an intervention that is gaining traction in the STEM community as an engagement tool. The SBL and PBL protocols for STEM learning are also being used in urban schools.

Capraro et al. (2016) in a longitudinal, mixed-methods study investigated the impact of urban secondary school STEM project-based learning on student achievement and teacher STEM professional development. The study collected observational data along with focus group interviews over a 3-year period on three high schools within an independent urban district where approximately 83% of the students were classified as low-income or poor. The students were predominantly Black (34.9%) and Hispanic (50.9%). The study was undertaken in all three high schools with a total of 3,754 students (after 47 students were lost due to attrition). The participants included high school STEM teachers. The intervention involved classroom observations of various PBL lesson plans using small-to-midsize groups before, during, and after their implementation over the 3-year study period.

Two groups of students were compared using propensity score matching where one group was given a low-fidelity PBL implementation and the other a high-fidelity
PBL implementation. High-stakes tests were used to evaluate the efficacy of PBL implementations on student achievement and teacher professional development. The qualitative study showed that the students who participated in small-group, high-fidelity PBL STEM programs demonstrated significant achievement (Cohen’s $d$ effects sizes between 1.41 and 2.03) on standardized test scores. The students who participated in low-level PBL programs demonstrated lower achievement (Cohen’s $d$ effects sizes between –0.16 and –0.08). The teachers perceived the benefits of small-to-midsize PBL classroom groups.

The study by Capraro et al. (2016) provided compelling evidence of PBL’s efficacy in improving student STEM achievement for high-fidelity PBL implementations in an urban classroom setting. Capraro et al. conducted a high-quality longitudinal study of significant sample size (albeit non-randomized) and strong treatment effects size values. Their results were generally consistent with the findings of Brown (2012) and Springer and Stanne (1999) on the benefits of active, small-group collaborative project learning. However, the study by Kezar and Gehrke (2017) only agreed with the findings of Capraro et al. on the beneficial impacts of delivering creative and stimulating instructional content. The lessons learned from these studies can be used to inform the development of strategies enabling the formation and growth of STEM schools exploiting the knowledge base of best practices to achieve desired STEM persistence outcomes.

Bruce-Davis et al. (2014) performed a qualitative study aimed at isolating the factors that contributed to a growth in the number of STEM schools. The study selected six diverse STEM high schools using the criterion sampling method and online reviews across varied geographical, socioeconomic, ethnic, and entrance criteria. An interview
protocol was conducted on school administrators, educators, and students to understand perceptions on STEM curricular and pedagogical strategies and institutional practices. The participants ($N = 3,174$, non-randomized) varied across gender, race, and socioeconomic status and included focus group interviews with 14 administrators, 47 teachers, and 74 students.

Several themes emerged from the Bruce-Davis et al. (2014) study: assuring a learning environment that is engaging and challenging, crafting curricula and practices that embrace real-world problems, and encouraging a nurturing environment that fosters active (hand-on) learning and significant teacher-student interactions (including formal in-school and informal outside-school support systems, activities, tutoring, mentoring, and other forms of accessibility). The findings were highly consistent with those reported by Brown (2012), Connors-Kellgren et al. (2016), Ernst et al. (2018), Kezar and Gehrke (2017), Proudfoot and Kebritchi (2017), Jackson et al. (2014), and Springer and Stanne (1999). The qualitative study was inductive, combining prior concepts and theories to determine students’ “STEM-readiness” and what interventions could be implemented to enhance engagement potential.

Bruce-Davis et al. (2014) also cited PBL as an effective STEM engagement protocol, thus supporting the findings and claims of Capraro et al. (2016) in the urban PBL study; additionally, Bruce-Davis et al. drew on Bronfenbrenner’s ecological systems theory as the basis for interventions (Bronfenbrenner, 1979). The study showed that academic and outside support systems operating within practical contexts helped students to develop STEM interests, skills, and a broader understanding of STEM which in turn, would spur the formation of STEM schools and programs. The study was of moderately
strong quality because of the significant sample size and where the findings could be reasonably generalized based on the diversity in geographical, socioeconomic, and ethnic data used. The Bruce-Davis et al. study leads to the notion of creating STREAM (STEM + Reading + Art) schools.

Scogin, Kruger, Jekkals, and Steinfeldt (2017) used a convergent-parallel mixed methods design to study the impact of experiential learning opportunities in STREAM on K-12 schools. Kolb (1984) defined experiential learning as a form of active pedagogy that draws on tangible experience and manipulatives combined with abstracting concepts. Experiential learning leverages aspects of problem-based learning and project-based learning. According to Savery (2006), problem-based learning integrated theory and practice in the study and solution of real-world problems. Scogin et al. stated that STREAM exploits the power of PBL, human-centric design activity, creativity, noncognitive skills development, and extracurricular education that connects students to real-world experiences and contexts.

In the Scogin et al. (2017) study, 73 middle school students applied for participation in a STREAM program during the 2014-2015 school year. A total of 60 students were selected via criterion sampling and only 57 students completed the year-long program due to attrition. About 140 students who were part of the control group in the study attended traditional classes. Qualitative data were collected from interviews conducted with students, STREAM teachers, and school leaders. Parents were given an online survey to complete. Quantitative ACT Explore test scores were then analyzed using multivariate analysis of variance (MANOVA) and analysis of variance (ANOVA) to isolate factors affecting the collaborative STREAM growth experience.
Scogin et al. (2017) found that students perceived STREAM experiential learning as motivating and enabled small-group collaboration for knowledge development and noncognitive skill growth; however, it had no major effect on standardized test achievement compared to their student peers who took traditional classes. The effects size study ($\eta^2 = 0.35$) and small sample size indicated a weak-to-moderate study that could not be readily generalizable, yet it offered new perspectives on alternative STEM interventions. The next section further expands on the fundamental points and ideas borne out by the Scogin et al. study towards the goal of operationalizing integrated, interdisciplinary STEM learning practices.

**Integrated, Interdisciplinary, and Interactive STEM Learning**

Various methods have been explored to establish a viable means of integrating the individual STEM disciplines. Lesh and Doerr (2003) and Lesh and Harel (2003) identified deficiencies in STEM pedagogy due to the individual STEM subjects being taught in isolation. Their idea traced its origins to John Dewey who argued against “teaching subjects isolatedly from each other” (Dewey, 1966, p. 189). Dienes (1960) extended Dewey’s concept emphasizing the importance of collaborative work, interactive social learning, and connecting to real-world studies of mathematics. Sriraman and Lesh (2007) reinforced the importance of teamwork and structural relationships in STEM learning that leveraged Dienes’ studies.

McGarr and Lynch (2017) examined ways to understand the synergies among the individual STEM subjects for the same purpose. Bernstein (1975) suggests the use of a *curriculum codes* framework whereas Bourdieu (1990) conceived a *cultural capital* model which states that schools should reward students based on their power or ability to
prioritize what type of knowledge is more or less important to them in performing a given task. Taken together, the models can be used to *classify* and *frame* the STEM cluster of subjects and apply them in an integrated way priority-wise to collaboratively solve problems. The models underpin key developments in the evolution of integrated, interdisciplinary STEM learning that continue to undergo refinement and testing. The next section delves deeper into the new, evolving paradigms for STEM learning.

**Empirical studies on new STEM paradigms and interventions.** Belland, Walker, Olsen, and Leary (2015) conducted a meta-analysis across 17 studies to investigate STEM education dependencies using scaffolding characteristics for secondary, college, and graduate students including adult professionals. For inclusion, the studies had to meet the following criteria: (a) encompass the desired student demographics; (b) compare a scaffolding intervention with a control group; (c) produce quantitative outcomes regarding cognitive, problem-solving ability, and conceptual knowledge; and (d) capture a sufficient amount of meaningful information for computing effects size. If competing sources were found with the same or highly similar data, the source with the least detail was excluded. A comprehensive review of scaffolding strategies culminated in 94 studies that were first identified as candidates for inclusion. When the inclusion criteria were applied, the 94 studies were reduced to 17 because of insufficient data to compute an effect size; a lack of obtaining quantitative, cognitive results; or the lack of a control group or conditions that denied or preempted a computer-based scaffolding intervention.

Belland et al. (2015) explored augmenting educator-based scaffolding through computer-based scaffolding to enrich problem-solving tasks. They attempted to measure
the impact of computer-based scaffolding characteristics (strategy, desired outcome, fading, and interventions), test score quality, and cognitive outcome scores in STEM education. The multimedia instructional intervention was shown to be associated with increased student learning by eliciting interest in the target task, helping students articulate the problem, and modeling expert processes that exploited “visible thinking.”

Using inferential statistics and meta-regression analyses, Belland et al. (2015) reported that computer-based scaffolding positively influenced learning (95% confidence interval limits for Hedges’ effects size $g = 0.53$). They further noted that as the methodological quality decreased for the meta-analysis studies considered, the effect size strength increased. Their study was deemed to be of moderately-high quality based on the measured effects sizes and confidence intervals (~0.1 – 1.1). A similar study investigated the impact of interdisciplinary scaffolding involving a restructuring of engineering and technology courses.

Mativo, Womble, and Jones (2013) examined integrated, interdisciplinary STEM scaffolding in a quantitative study that measured students’ perceived educational value and perceived personal value of taking integrated engineering and technology (E/T) courses versus taking separate E and T courses. The combined E/T model helped to explain how students perceived the value of integrated STEM course structuring with expert mentoring. Most of the students surveyed perceived a high value for the combined E&T courses driven by achieving career goals, being exposed to challenging courses for self-improvement, teacher competency to motivate learning, and parent influence. Most students also perceived high personal value in E/T courses based on their learning interest and college/work readiness. The Mativo et al. study was of moderately high quality.
In a longitudinal, mixed-methods study, Fan and Yu (2017) examined the impact of an integrative STEM intervention (as the independent variable) that merged engineering design with technology classes in Taiwanese high schools. Using a quasi-experimental design, they measured learning performance of the students partaking in the STEM engineering module (the experimental group) compared to the students who participated in the technology-only education module (the control group). Learning performances were measured against acquired knowledge or conceptual understanding, critical thinking abilities, and design project achievement as the dependent variables. Fan and Yu used convenience sampling across two high schools, where a total of 332 students 16 to 17 years of age were selected to participate in the study (no attrition was reported). The control group (CG) was assigned to one of the high schools and the experimental group (EG) was assigned to the other high school. The CG and EG groups were each subdivided into five subgroups for a total of 10 classes, with 161 students in the CG subgroups and 171 students in the EG subgroups. The CG and EG subgroups had about an even distribution of male and female students and both schools recruited high-achieving students based on acceptance tests to assure a fair comparison.

Fan and Yu (2017) used measurement instruments that included: a design project rubric (for a Lego model); Mechanical Conceptual Knowledge Test (MCKT) pre/post-test and High-order Thinking-skills Test (HTT) post-test (the dependent variables in the quantitative data analysis); semi-structured interviews; and qualitative observations. An analysis of covariance (ANCOVA), analysis of variance (ANOVA), and t-tests were used to measure the statistical significance between the pretest and posttest for the MCKT and HTT protocols. The participants in the STEM engineering module showed significantly
improved learning performance compared to their counterparts, demonstrating the positive effect of the integrative STEM intervention.

The findings by Fan and Yu (2017) and Mativo et al. (2013) were consistent with the meta-study by Belland et al. (2015) on the efficacy of scaffolding, but across a different set of integrative and disciplinary dimensions. Fan and Yu’s study was deemed to be of high quality based on the significant effect size of the MCKT total scores that demonstrated the strong effect of the independent variables on the dependent variable (correlation coefficients between 0.61 and 0.76, average effects size $r = 0.2$, average $t$-test values on the order of 10, and $\eta^2$ between 0.05 to 0.16); however, due to the non-random sampling and the limited number of schools considered, the generalizability of the study was uncertain. Student perception as a variable is further examined next.

Whalen and Shelley (2010) quantitatively studied students’ perceptions of multidisciplinary STEM and non-STEM scholastic support systems including teaching and mentorship support. The study’s goal was to determine how these forms of scaffolding influenced their decision to graduate with a STEM certificate/degree or to switch to a non-STEM major. The study found that the main predictor of the effect was the student’s Grade Point Average (GPA) received during their last term. The Whalen and Shelley study was deemed to be of moderately-high quality based on the appreciable sample size (albeit, non-randomized) with average effects sizes (odds ratios) exceeding the 1.5 – 2.0 range, and the correlation coefficients ($\beta$) generally varying by more than $+/−$ 0.5. The predictors of student achievement and engagement and the importance of educator or institutional support in their study resonated well with the scaffolding
findings of Belland et al. (2015) and Mativo et al. (2013). Additional studies further
examined institutional support for STEM integration and engagement.

A qualitative study by Roehrig, Moore, Wang, and Park (2012) investigated the
feasibility of integrating STEM lesson plans in secondary schools and to connect the
plans to other disciplinary learning activities. Their qualitative findings pointed to an
increase in students’ STEM learning performances based on teachers’ observations when
the lesson plans were implemented, although it was unclear how interdisciplinary
learning influenced the results. The strength of the study was deemed moderate at best
per the limited sampling regime and research method used.

Kertil and Gurel (2016) further conceptualized an integrative STEM pedagogy
drawing on the findings of Roehrig et al. using PBL with mathematical modeling
activities. Kertil and Gurel highlighted the merits of content integration (guiding
educators via flexibly structured STEM curricula) and context integration (teaching how
a main subject relates to other disciplines without forsaking the uniqueness of the main
subject) in their conceptualization. Applied STEM also played a role in these studies as a
means of ensuring practical contexts for integrated, interdisciplinary STEM learning.

In a quantitative study, Gottfried (2015) highlighted the advantages of introducing
applied STEM courses into high school curricula to provide practical, real-world contexts
that built upon science and math concepts which students learned previously through
traditional instruction. Gottfried demonstrated a direct, positive correlation with
reinforcing STEM persistence through this form of scaffolding, constituting a
moderately-high-quality study based on the average effects size (odds ratios across key
dimensions on the order of 1.5 – 2.0 or higher) and significant sample size. They pointed
to the need for practitioners and policymakers to extend STEM curricula for this purpose. Gottfried’s findings agreed with those of Belland et al. (2015), Mativo et al. (2013), Roehrig et al. (2012), and Whalen and Shelley (2010) on the need for best practices, interventions, and reforms to reinforce multiple levels of institutional scaffolding especially in high schools and to encourage active (hands-on) learning.

In a quantitative study, Christensen, Knezek, and Tyler-Wood (2015) found that active engagement in science instead of passive textbook learning made a significant difference in persistent STEM engagement. The choice of curriculum delivery and classroom environment were cited as key factors for STEM-disposed students. Science, and for that matter any STEM subject, was best learned when presented in an active learning environment and in a real-world context. The research findings of Christensen et al. implied interactive learning with real world contextual relevance could evoke positive STEM outcomes. The quality of the study was high based on the strong sample size and treatment effects sizes (generally in the range of 0.15 – 0.6), although the findings dependent on age, gender, and other factors were not reported.

The Christensen et al. (2015) study was consistent with the findings of Belland et al. (2015), Gottfried (2015), Mativo et al. (2013), and Roehrig et al. (2012) on the importance of applied, interactive learning and content delivery that draws on real-world contexts. Sanders (2012) underscored the significance of integrative STEM learning and emphasized using applied mathematics to solve real-world problems as a best practice. Allen, Webb, and Matthews (2016) complemented the findings by suggesting an adaptive STEM learning approach that builds upon STEM-related conceptual development, inquiry, and practical contexts. According to Allen et al., adaptive STEM pedagogy
assumed educators had command of the content, could effectively convey knowledge, possessed a constructivist attitude, were visionary, encouraged students’ emotional investment, and could negotiate lesson plans to meet students’ learning needs. They presented a moderately-high-quality, in-depth case study in narrative/descriptive form that illustrated the merit of the approach. The Allen et al. study inferred that teacher constructivism can lead to creative curricula that “fuse” concepts for a transdisciplinary learning approach.

Flogie and Aberšek (2015) defined transdisciplinarity as the “fusion” of many disciplines and the creation of new “subsidiary” disciplines by applying a dynamic meta-structure and ontological approach that accounted for adaptation. They used neuroscience, cognitive science, and education to explain the advantages of combining disciplines for deep learning. Flogie and Aberšek suggest that such a transformation of the STEM classroom aligned well with a cognitive neuroeducation model approach. They conducted a mixed-methods study to evaluate a transdisciplinary pedagogic model and curriculum that used modern information and communication technologies to crosspollinate knowledge, enable collaboration, spur critical thinking, and foster creative problem-solving for all study participants.

The study by Flogie and Aberšek (2015) lasted 2 years and was conducted across nine elementary and secondary schools to measure the attitude of students and teachers exposed to a transdisciplinary cognitive neuroeducation model in an actual classroom environment. A control group and an experimental group were established to measure the impact of the intervention. Performance data were acquired via a questionnaire. A simple random sample of 100 students (42 females and 58 males) was drawn from a
population of approximately 2,000 students from 10 randomly chosen lower secondary schools (suburban and urban). After attrition, the final sample size was 88. Also, 20 educators participated in a qualitative research phase of the study. Data from a complementary study on 4,373 students from 450 lower secondary schools were collected and statistically analyzed for the control group. Using independent t-tests and the 95% confidence intervals for the differential means, the findings showed that the students looked forward to attending class knowing that an innovative curriculum would be taught ($t = 0.475, p = 0.02$). The study was deemed of low-moderate quality.

Henrkisen, DeSchryver, and Mishra (2015) extended the concept of transdisciplinary learning by introducing the concept of synthesis in two basic forms: *synthesis for meaning* and *creative synthesis*. The syntheses have theoretical and practical value for STEM pedagogy using technology, mathematics, and digital tools. The empirical study, which was of a descriptive type, cited seven transdisciplinary skills for creative thinking that included perception, patterning, abstraction, embodiments, modeling, playing, and synthesis. The transdisciplinary skill set encapsulates the ways in which creative people think and points to how this model could be applied to the STEM classroom to enhance engagement.

The next section expands upon the idea of interdisciplinary, cross-disciplinary, or transdisciplinary STEM learning by capitalizing on the interconnections across seemingly disparate disciplines through mathematical relationships. The role of mathematics in integrated, interdisciplinary STEM learning is universally accepted as a means of better understanding how STEM learning and engagement could be enhanced. The premise of the following discussion is that mathematics acts as a framework for STEM engagement.
Expanding STEM Learning by Leveraging the “M”

STEM and many non-STEM subjects share a common mathematics framework. For example, music or music theory, performance art and improvisation, media arts, kinesthetics or physical motion, and a variety of other non-STEM areas are deeply rooted in mathematics. Often, the same mathematics can be applied to the disciplines of science, technology, and engineering. A shared mathematics framework connects the domains to describe a set of common behaviors or characteristics. Hence, one could infer that a grasp of mathematics is a step in the right direction for increased STEM engagement by combining the science with the art. Several empirical studies were identified that sustained this conjecture as discussed next.

Empirical studies on leveraging a mathematical framework. Tobias (2014) suggests that the diversity and creativity in engaging with music via digital media, technology, and math allowed one to “create music through experimentation,” including the application of theory and mathematical constructs. Tobias stated, “Music education may be experiencing a transition period” in view of the growing STEM movement. He cited the example of a recent college course entitled “Comprehensive Music and Interdisciplinary Arts” as a sign of the transition.

Moyer, Klopfer, and Ernst, (2018) qualitatively applied the Tobias (2014) concept for at-risk junior high school students who were tasked with solving computer technology design challenges that drew on the intersection of musical creativity and technological dexterity. Although the quality of the study was low-to-moderate and its power low based on a small sample size, it illustrated how interests in both music and programming logic can be developed within a small group while learning skills in each discipline. The
outcome was a rich learning experience that combined computer technology, math, audio engineering, and performing arts to solve a real problem.

In a large-scale longitudinal study, Korpershoek, Kuyper, van der Werf, and Bosker (2011) investigated the extent to which science students’ GPAs on advanced STEM tests were influenced by their math aptitude. They quantitatively compared the science students with average math aptitude with those of students who took final exams in advanced STEM and other subjects. Regression analyses revealed that cognitive ability and achievement motivation were the top two predictors of students’ GPA achievement. The study was of moderate quality where the Cohen’s $d$ effect size for the difference was 0.8. The researchers demonstrated how math aptitude and achievement motivation affected attitudes and performance in advanced STEM education.

Using national survey data, Moakler and Kim (2014) quantitatively examined confidence and background/control variables as predictors in selecting a STEM major by incoming college freshman with a focus on mathematics. Their logistic regression analyses revealed that the dominant predictors in choosing a STEM major were (a) mathematics confidence, (b) scholastic aptitude (including aptitudes in non-STEM subjects), (c) parents’ STEM profession, and (d) GPA. Mathematics confidence and academic performance were found to be the major influential factors. Moakler and Kim’s study was of moderately high quality based on the power (sample size) and effects size values over the background/control variables of interest in the study.

Interdisciplinary conceptualizations with math at the center have been studied to further illustrate the methods of exploiting cross-disciplinary synergies such as between math and kinesthetics. For instance, Hutto, Kirchhoff, and Abrahamson (2015) showed a
strong relationship between learning math and learning sports. They drew on the radically enactive and embodied approaches to cognition (REC) rooted in sports psychology to explain how learning athletic skills can be likened to the human brain’s capacity to develop math aptitude. The link highlights the synergies between sports and mathematics and the association to STEM learning and the brain by examining how individuals interact with and adapt to dynamic environments (a form of problem solving). Hutto et al. suggest that the REC concept can be used to understand the process of STEM deep learning and reinforcement learning. Spatial training such as spatial visualization, mental rotation (visualizing an object spinning about an axis and viewing it from different perspectives), and perspective taking is akin to sports training and math learning involving geometric and physical dimension virtual manipulation.

Spatial training has been purported to increase STEM engagement because both domains of sports training and math learning involve active reasoning and problem-solving over multiple degrees of freedom (Stieff & Uttal, 2015). According to von Károlyi (2013) and Stieff and Uttal, interventions that enhance a student’s spatial ability should increase STEM performance. Additionally, von Károlyi found robust relationships between STEM achievement and spatial abilities such as mental rotation and three-dimensional visualization. Stieff and Uttal related spatial training to concept generation (CGN) that leverages mathematical modeling in practice. White, Wood, and Jensen (2012) quantitatively studied the efficacy of CGN techniques for engineering design tasks in small team settings (control and experiment groups) that involved detailed, iterative brainstorming with mind-mapping and morphological analyses. The
techniques applied mathematical skills and used computer graphics modeling that involved the generation and analysis of geometrical shapes.

According to White et al. (2012), a metric for success was an increase in the number of new concepts developed compared to teams that did not leverage mathematics or computer science. Eighty-six student surveys were recorded to capture new concepts producing over 1,500 data points from the survey questions. The results of comparing the control and experiment groups showed about an average 15% increase of new concepts as the teams progressed through the CGN process. Although the CGN ideation techniques have merit, the study by White et al. was considered of weak-to-moderate quality and deemed inconclusive.

Next, Gold et al. (2018) quantitatively assessed the spatial reasoning skills of 345 U.S. students enrolled in introductory geology courses ($n_1 = 277$) and advanced structural geology courses ($n_2 = 43$) plus a third group of undergraduate students ($n_3 = 25$) as a comparison group to evaluate their STEM affinity and aptitude in mathematics. A test was administered to measure the students’ abilities to analyze visuospatial representations and to spatially manipulate and mentally rotate three-dimensional (3-D) objects. Using nonrandomized convenience sampling, an uneven distribution of test scores was recorded in which 6%-75% of the questions were correctly answered. The tests showed that cognitive spatial manipulation was not an innate skill and must be acquired through experience and practice.

Indeed, an affinity for STEM learning and motivation to pursue STEM fields was found to positively correlate with spatial skills ability gained through informal, recreational activities during childhood such as playing action-, sports-, or construction-
type video games or through playing music—activities that are inherently mathematically rich. Gold et al. (2018) hypothesized that formal education or training in spatial reasoning, in which students are connected to and made to interact with real-world environments, could enhance STEM opportunities particularly for women. An inspiration for the Gold et al. study was the embodied cognition theory that states, “The brain is dynamically connected to the environment.” Additionally, their study suggests that personal characteristics (gender, motivation), academic preparation, and recreational experiences could contribute to spatial skills development and nurture STEM affinity (Uttal et al., 2013).

To test the above theories, Gold et al. (2018) administered a three-part, empirically based evaluation instrument starting with a pretest baseline using the statistically validated Motivated Strategies for Learning Questionnaire (MSLQ). The MSLQ was used to gather demographic, academic, and experiential data on the sample population. The pretest stage was followed by two rounds of spatial reasoning tests as an intervention. Inferential descriptive statistics were computed, and ordinary least squares regression analyses were performed yielding small-to-medium effect sizes (Cohen’s $d$ values within the range $0.18 \leq d \leq 0.42$).

Gold et al. (2018) concluded that (a) many STEM students leave high school without adequately having developed spatial reasoning skills; (b) students who were motivated to learn and exhibit strong self-efficacy because of their learning success developed better spatial reasoning abilities than did the less motivated students; (c) STEM majors exhibited greater spatial skills than do non-STEM majors, although causality remained in question; and (d) spatial reasoning skills were not typically gender
specific and were influenced by sociocultural experiences as opposed to biological factors. The study also showed that cognitive spatial abilities could be further enhanced through periodic systematic testing and formal training throughout K–12 and college; such a regimen could encourage confident STEM pursuits and lead to positive outcomes.

In a high-quality quantitative study, Mullender-Wijnsma et al. (2015) identified the relationship between learning and kinesiology and increased math and reading performance coincident with physical activity. DiTullio (2018) cited a study by Medina (2014) that characterized physical movement as “cognitive candy.” Jensen (2008a) suggests that a mood enhancing, dopamine-like neurotransmitter is released in the human bloodstream during physical activity stimulating new cell production in the brain and creating the so-called “runner’s high” effect that enhances learning and retention. DiTullio further identified a wealth of quantitative and qualitative evidence in the body of literature on the importance of physical activity and learning capacity (Donnelly & Lambourne, 2011; Sattelmair & Ratey, 2009; Shephard & Trudeau, 2005).

A much different point of departure was offered in a quantitative study by Bonny, Lindberg, and Pacampara (2017) that explored the relationships between dance, cognitive processes within the brain, and STEM engagement with emphases on spatial training and mathematics. The findings of Bonny et al. can be readily contrasted with those of Hutto, et al. (2015), Stieff and Uttal (2015), von Károlyi (2013), White et al. (2012), and Gold et al. (2018) for a broader understanding of the connections between spatial abilities, shape or object artifact mental rotation, kinesiology, and STEM achievement. The Bonny et al. study closely examined associations between urban dance styles and STEM learning.
Particularly, Bonny et al. (2017) postulated a possible link between hip hop dancing and STEM learning and sociocognitive abilities in young adults across several demographic and experiential control variables. They drew on prior studies that showed a positive correlation between playing video and brain games and kinesthelic performances (sports, music, and classical dance) on cognition ability. For instance, the activity in brain regions responsible for cognitive-motor tasks significantly increased in professional classical ballet dancers when they watched ballet-specific dance routines.

In the study by Bonny et al. (2017), non-classical dancers were recruited to undertake a series of computer-based tasks designed to measure STEM and social cognition using a set of dependent variables. The specific dependent variables identified were (a) the start age of dance practice and self-ratings of hip hop dancing and pedagogical competence, (b) working memory block score, (c) total number of blocks one recalls correctly for a given computer task, (d) number of extra moves beyond a minimum number of moves to complete a computer task, (e) accuracy of responses, and (f) reaction time for computer-based responses. The independent variables were active memory capacity, mental rotation speed (the rate of spatial manipulation), problem-solving efficiency, and theory of mind (emotion processing, empathetic attitude, or disposition).

Bonny et al. (2017) recruited 60 participants post-attrition of varying age, ethnicity, gender, geographic location, academic background, and hip-hop dance experience using non-probabilistic convenience and criterion sampling. A Likert-scaled questionnaire was used to quantify distributions across the control variables. The performance of each computerized task was calculated using linear mixed and linear
regression models and the maximum likelihood method that accounted for individual differences in performance for fixed and random mutual effects between independent variables. To assess the mutual interactions and performance differences, mixed-factor analysis of variance (ANOVA) descriptive statistics were computed using the Satterthwaite approximation method. The effect size estimates were based on an approximation of variance metric. The study was deemed to be of medium quality despite the strong main effect of set length ($0 < F_{values} < 305.98$) and effect size ($-0.412 \leq r \leq 0.783$) because the sample size was relatively small and geographic diversity limited.

Those individuals who specifically had hip hop dance experience were found to be more adept and accurate at mental spatial manipulation (cognitively faster at detecting and discerning patterns and pattern changes); however, they identified only marginally with positive emotions when controlling for “dance style” and sociocultural demographics (Bonny et al., 2017). Although no discernable impacts of the hip-hop experience were observed on working memory capacity or problem-solving efficiency, the dance style positively correlated with improved STEM cognition and skills, particularly in reinforcing math aptitude. Bonny et al. further suggest that the fine arts, through the lens of hip-hop dance art and culture, could be an effective STEM engagement device and enhance sociocognitive skills through youth-based collaborative group activities. They concluded that hip hop dancing could effectively augment the STEM learning experience. The findings and conclusions by Bonny et al. paralleled those of Hutto, et al. (2015), Stieff and Uttal (2015), von Károlyi (2013), White et al. (2012), and Gold et al. (2018) on the relationships between spatial abilities, mental rotation, and overall STEM achievement.
Next, several studies examined how self-efficacy, self-concept, and self-confidence influenced one’s decision to pursue a STEM major, particularly in the field of mathematics. In a study by Sax, Kanny, Riggers-Piehl, Whang, and Paulson (2015), math self-concept (MSC) was found to be a key predictor of STEM engagement. The quantitative study used a national sample of entry-level college students over a 4-decade period to measure MSC variances across STEM majors. The study suggests that low math confidence is a likely STEM deterrent. Sax et al. also found a strong link between MSC and self-efficacy drawing on social cognitive career theory (Lent, Brown, & Hackett, 2002). MSC revealed itself as a dominant predictor of one’s decision to major in a STEM field holding all other predictors constant. The study was deemed of generally high quality based on the sample size and effects size metrics.

Whereas the Sax et al. (2015) study focused on math self-concept, Peters et al. (2017) conducted a longitudinal study to test a values-affirmation manipulation intervention designed to improve numeracy (math self-confidence and literacy). In the study, undergraduates participating in a psychology statistics class were randomly segregated into control and experiment groups. The study showed positive STEM outcomes evidenced by course grades and an increase in math-intensive course pursuits, including improvements in abstract numeric reasoning ability based on tests, surveys, and evaluations conducted. Peters et al. concluded that individuals with greater numeracy ratings were more apt to pursue STEM careers. The results also showed that the study participants on average took classes that were more math-intensive pre- than post-intervention after a 2-year follow-up period. The study was deemed of high quality based
on the experimental design, method and control, sample size, and inferential statistics ($\eta^2 = 0.092; 95\% CI: 0.09, 1.25$).

Wang and Degol (2017) offered an alternative perspective drawing on collective self-efficacy values that stressed one’s innate abilities, affinity, and motivation to engage in STEM or to pursue a STEM career, focusing on the problem of female underrepresentation in the field of mathematics. The meta-study by Wang and Degol further investigated how sociocultural and biological factors could potentially affect cognitive capacity and STEM motivation in accordance with their expectancy-value theory and mindset theory to address the central issue. Expectancy-value theory points to the belief that females generally have less of an affinity for mathematics because of a perceived lack of self-efficacy compared to their male counterparts. Mindset theory suggests a psychological, self-perceived belief in the “fixed” stereotype notion that math ability is gender dependent, which can lead females to think they naturally lack math aptitude or achievement potential. The theories are considered controversial in their application to explain why females may avoid challenging STEM careers.

Wang and Degol (2017) addressed gender factors across six empirically supported areas through the meta-studies, namely (a) innate cognition, (b) relative cognition, (c) occupational affinities, (d) lifestyle values or personal preferences, (e) self-efficacy beliefs, and (f) gender bias factors. Wang and Degol’s meta-analysis along the six dimensions yielded findings that revealed subtle links between biological and psychological determinants and sociocultural experiences that can influence self-efficacy and life and career aspirations. Their study was deemed of moderate-to-high quality based on the considerable effect sizes (Cohen’s $d$ in the range $0.34 \leq d \leq 1.11$). Su,
Rounds, and Armstrong (2009) also related gender perspective differences and self-efficacy values to occupational interests or pursuits. For instance, their study determined that males had an affinity for working with or manipulating objects, whereas females preferred to work with other people. The finding may in part explain how self-efficacy, self-perception, and self-belief bear on one’s life and (STEM) career decisions.

According to Wang and Degol (2017), the link between biological and psychological processes and sociocultural experiences and expectations has significant implications. It can greatly shape one’s perspectives on life values and aspirations, social identities and connections, and the desire to build competencies for success. The meta-study suggests that gender differences in average math ability are most profound during the mid-to-late adolescent or young adult period. Furthermore, Wang and Degol found that relative cognitive strength (for example in mathematics or verbal communications), tended to influence STEM career paths more than absolute cognitive ability in only one subject area, which they believed would explain the dearth of females pursuing math-intensive careers.

The findings by Wang and Degol (2017) were consistent with those of Peters et al. (2017) and Sax et al. (2015) on the connection between self-concept and self-efficacy and the regimes of cognitive development, motivation, and career decision-making. Wang and Degol further proposed that policies and practices could be leveraged to increase STEM diversity for expanded engagement. Chapter 5 will address how policies and practices can be used to advance STEM engagement along these and related fronts. Next, the relationships between mathematics, music, brain learning, and STEM engagement in young adults will be more closely examined.
Cognitive-Creative Brain and Math-Music Connection in STEM Learning

A keen insight into the fundamental neuroscience of the adolescent/teenager and young adult brain and how it “learns” can inform the recommendation of new strategies or interventions for improving STEM education, engagement, and persistence. The discussions which follows are not intended to provide an in-depth treatise on the brain or neural-based learning, and the specific medical or clinical details are deliberately omitted. Instead, a high-level perspective of how the brain learns, in the presence of musical stimuli, will be presented to provide a basic understanding of music’s effect on the brain, including the underlying mathematical descriptors influencing cognition and creativity, and how music as an art form can be used to motivate STEM engagement. Additionally, the functions of the left-side (logical, cognitive) and right-side (creative, artistic) lobes of the brain will be differentiated to emphasize the power of integrated learning, the cognitive-creative synergies that exist, and the effect on STEM engagement.

Although the present research is broadly interested in K-college STEM engagement and persistence, of critical interest is the population of students 17-22 years of age generally representing high school seniors through college graduates. Despite efforts at stimulating STEM interest at an early age in elementary, middle, and junior high school, some concerns immediately arise. For instance, the maturity level, emotional capacity, and the ability of pre-adolescents to make informed, sound decisions regarding STEM careers can be called into question. Research in pre-adolescent STEM engagement would seem to require a different evaluative lens altogether that would examine how physical, psychological, physiological, socioeconomic, and sociocultural
background factors affect aspirational choice-making. Hence, pre-adolescent STEM engagement will not be the focus of the present research.

Returning to the age demographic of interest, members of this population may or may not be STEM-oriented or even be in the STEM pipeline. For those students in the pipeline, the desire is to keep them on a path towards a rewarding STEM career; for those students not in the STEM pipeline, the goal is to engage their interest in STEM for the reasons given in Chapter 1. One way of achieving the goal is to begin with a deep examination of the connections between music, mathematics, and neuroscience to illustrate the cognitive-creative brain functions and capacities; although, other non-STEM disciplines including dance and visual art forms can equally be considered. Exploring the role of art forms such as music can help to increase our understanding of the subtle relationships and profound influences on brain learning and STEM engagement. Before delving into the music-math-brain synergy, first consider several contemporary viewpoints and philosophies on the role of non-STEM subjects and mathematics in the STEM curriculum.

Physical reality is described through the lens of mathematics hence, in theory, everything in the detectable universe can be described mathematically. Recall however, that conventional STEM curriculum often teaches high-level mathematics as a standalone subject; consequently, it takes on a “quantitative” character—abstracted or detached from real-world contexts. According to Wynn and Harris (2013), the art-disposed or right-brain-oriented student in this case can become math-disengaged or arithmophobic, although this is more of an exception than a rule. They believed that an interdisciplinary, collaborative environment could help one embrace and overcome the fear of math.
Wynn and Harris (2013) stated that a reciprocal benefit exists in joining artists (visual thinkers) and athletes (strategic thinkers) with mathematicians and scientists. Einstein was a scientist and a vivid visual thinker. Apple’s Steve Jobs was a visionary entrepreneur who linked technology with simple, artistic design and creative elegance. Wynn and Harris went on to state that “The best art students and most successful artists are those who have developed high levels of technical skill, and who are intellectually sophisticated” (p. 58). They also declared that “Art students become better technicians and conceptual thinkers though STEAM, while science students become more imaginative and innovative” (p. 58).

Be it art, design, or the humanities in general, the non-STEM subjects offer a glimpse into human nature, likes and dislikes, emotions, and habits that relate to how one thinks and learns and the associated brain activity. The perspective is equally relevant to the art of music and its relationship to mathematics. The synergies reveal insights into the power of motivational learning, experiencing and handling failure, embracing challenge, understanding self-capacity and self-efficacy, seeking cultural enrichment, and growing and evolving as an individual.

Wynn and Harris (2013) cited several examples that demonstrated the above aspects in educational contexts. For instance, in 2010, the Hampton University Museum and School of Science, Engineering, and Technology held an event called “Jam Session: Jazz and Visual Art in Engineering” that demonstrated the link between improvisational jazz and engineering design principles. Forums like this raise the question, “How does such a process unfold in the human brain and can the knowledge of this be used as a tool to help meet overall STEM engagement goals?” This aspect is further explored next.
According to Eagleman (2015) and Kelly (2012), the brain continues its growth and development well into young adulthood. Kelly pointed out that the brain has a staggering estimated $10^{11}$ neurons; additionally, each neuron has an average of 10,000 connections allowing it to link to other neurons, producing some $10^{15}$ connections that comprise a highly complex neural network (Reimer, 2004). The neural systems underlying emotion, motivation, and cognition are in a constant state of flux until one’s early-mid 20s in age. Eagleman (2015, p. 50) likened the brain’s neural system to a busy city that is constantly adapting and changing to environmental stimuli and that directly interacts with the emotion and values-based reward centers. The phenomenon is manifested as increased brain activity and “learning excitement” over a stimulating event or experience. Neural populations distributed throughout the brain’s left- and right-hand neural network system compete for control (Eagleman, 2015, pp. 104-106).

A study by DiTullio (2018) offered a compelling, alternative perspective on brain-based strategies in education with potentially significant implications for STEM pedagogy. According to the study, brain-based learning theory, which first emerged over 20 years ago, defined the optimal state for learning through an understanding of the integration between neuroscience and education (Zadina, 2015). DiTullio cited several studies by Caine and Caine (1994), Jensen (2008a), and Jensen (2008b) that suggest brain-based interactive learning environments promote individual creativity, conceptual understanding, and disciplinary connections. Such environments, per DiTullio, provide for “relaxed alertness, orchestrated immersion, and active processing.”

DiTullio (2018) further stated that, “the goal of brain-based learning is to align teaching and learning with how the human brain is biologically organized for learning,”
adding that, “humans learn best in a state of relaxed alertness.” The result can only be achieved if the threat-to-challenge ratio is kept low (Tokuhama-Espinosa, 2011).

Similarly, Neve (1985) described the importance of minimizing the threat by curating environments that nurture interactive communication, idea sharing, and learning through real-life problem-solving engagements.

Hart (2002) and Neve, Hart, and Thomas (1986) also underscored the importance of integrating neuroscience and education derived from multiple disciplines such as archaeology, anthropology, evolutionary science, computer science, and other subjects. DiTullio (2018) referenced a high-quality quantitative study that demonstrated brain-based learning approaches had a significant, positive impact on students’ willingness to learn challenging science content (Saleh, 2011). Hart on the other hand likened the human brain to the digital computer in its ability to store programs and execute tasks amidst multiple environmental stimuli including the presence of “threats.” The above findings on brain-based learning strategies were consistent with those of Eagleman (2015), Kelly (2012), and (Reimer, 2004).

To gain a deeper understanding of the mechanisms involved in learning management and coping with threats, consider the following. Whereas the human brain is generally subdivided into six basic parts, including various subareas and functions, three main areas are emphasized in the context of STEM learning and engagement. The main areas of interest are the cerebellum, amygdala, and prefrontal cortex. Eagleman (2015) and Kelly (2012) described the functional areas of the brain and the lobe structures as follows (see Figure 2.1):

- Frontal lobe controls behavior, intelligence, memory, and physical movement;
• Parietal lobe controls intelligence, language, reading, sensation, and shares in intelligence (includes Broca’s area and Wernicke’s area);

• Occipital lobe is responsible for vision;

• Temporal lobe controls behavior, hearing, speech, memory, and shares in vision;

• Cerebellum handles balance and coordination; and

• Brain Stem monitors and manages blood pressure, breathing, heartbeat, and other autonomic and reflex functions.

According to Eagleman (2015) and Kelly (2012), the left brain controls the right-side body and focuses on skills related to mathematics and numbers, science, logic or reasoning, analytical problem-solving, written and spoken language, and objectivity. On the other hand, the right brain controls the left-side body and focuses on interpreting 3D shapes, art and music awareness, synthesis, intuition, creativity, imagination, subjectivity, emotion, and pattern recognition. The corpus callosum is a C-shaped nerve bundle located underneath the cerebral cortex that extends across the brain midline and connects the two cerebral hemispheres. The corpus callosum is an important conduit in understanding how the “objective” side of the brain interacts with the “subjective” side in the presence of external stimuli and the outcomes on learning and engagement.

Eagleman (2015, p. 15) stated that as children enter adolescence or young adulthood, the brain exhibits a growing response to stimuli that excite the reward centers of the brain associated with pleasure seeking. Clearly, any threats that countermand reward or detract from pleasure-seeking are dealt with in a fight or flight way where one either copes with the threat or resigns from the challenge. According to Eagleman, the
pleasure and reward centers of the brain are associated with the midbrain dopamine system that transmits signals which assign a *value* on choice-making affecting how one learns via right- and left-side information acquisition and synthesis processes (p. 118).

An overstimulating learning environment can overwhelm and potentially traumatize young children who then exhibit unhealthy and difficult behaviors including anger, withdrawal, frustration, or apathy. Perry’s neurosequential model is a brain-based and trauma-informed clinical approach that can aid in understanding how trauma faced in
any environment or situation, such as a stressful classroom, could be managed (Perry, 2002). Figure 2.2 shows an inverted pyramid that corresponds to brain development at different stages of a child’s growth starting from the base or brain stem. For instance, as a child matures, his/her brain-based behaviors evolve from an instinctual response, to an emotional response, to eventually achieving self-control and self-management.

![Figure 2.2. Perry’s neurosequential model showing the progression of a child’s neural development and its impact on behaviors including effects on learning capacity. Adapted from “Childhood Experience and the Expression of Genetic Potential: What Childhood Neglect Tells Us About Nature and Nuture,” by B. D. Perry, 2002. In *Brain and Mind*, 3 (pp. 79-100). http://centerforchildwelfare.org/kb/ChronicNeglect/ChildExperience.pdf](image)

Perry (2002) showed that modifying the stimuli, such as introducing art or music to an otherwise stressful environment, can help reverse undesirable behaviors or responses. The responses and interventions were gauged based on the child’s age and stage of brain development. This brain-based model can inform educators of strategies or
interventions to engage their students in STEM. Next, the findings in this section on brain-based learning processes are further extrapolated to encompass the introduction of STEM and the art form of music.

**Empirical studies on brain learning capacity, STEM, and the arts.** The cerebellum, which supports higher learning functions and complex social skills, is located at the rear-base of the brain and undergoes significant changes both during and post-adolescence in terms of an increasing growth in the number of neurons and neural interconnections. Next, the amygdala, which is located deep at the center-base of the brain, is responsible for primal feelings, emotions, and reactions. According to Kelly (2012), adults rely more on the rational prefrontal cortex, located at the front-center of the brain just behind the forehead, which is underdeveloped in teenagers and is the last area to mature. Hence, the focus shifts to the brain learning mechanisms, plasticity, and enhanced cognitive-creative associations based on experiential factors associated with music and related influences as interpreted through the “M” in STEM.

Recall the qualitative study by Payton et al. (2017) that addressed the experiences of college students who were enrolled in an interdisciplinary STEM and dance arts curriculum; the study cited similarities and associations between the art of dance and STEM problem-solving, collaboration, and critical thinking tasks. Their study essentially showed that dance could expand one’s understanding of the interconnections between the STEM and art domains that in turn could help broaden STEM engagement by also making it “fun.” Also recall that Grant and Patterson (2016) suggest in their qualitative study that the arts animate learning due to their experiential nature and because they stimulate creativity and critical thinking, which are equally valued in STEM pedagogy.
Could this viewpoint similarly apply to the *art of music* and the *science of sound* bridged by a common mathematical framework?

Carrese, Kim, and Creeden (2013) stressed the importance of interdisciplinary learning in STEM that embraced the humanities. They cited other luminaries such as Leonardo da Vinci, Nikola Tesla, and Albert Einstein who were inspired by the humanities. Indeed, the violin was a muse for Einstein inspiring his scientific thought experiments in relativity. Einstein said, “Look deep into nature, and then you will understand everything better” (Hummell, 2014, p. 32). Daugherty (2013) provided further evidence that science Nobel laureates were four times as likely to be musicians. Quoting Arne Duncan, U.S. Secretary of Education, Daugherty underscored the benefits of increased arts participation in school STEM programs as follows:

> For today’s students to be the innovators and economic leaders of the future, they will need to have experiences as musicians and dancers, painters and sculptors, poets and playwrights—in short, they will need to be creative innovators who will build our nation’s economy for the future. (PCAH, 2011, p. 3)

Slater et al. (2017) quantitatively studied brain plasticity using the *musician signature of expertise* measure as a key performance metric (KPM) to help answer the question on the synergy and effects of the art of music on the science of sound. They compared the cognitive and sensory processes in musicians and non-musicians using a total convenience sample size $N = 60$ individuals recruited from the U.S. Midwest. Their research, along with data collected from longitudinal studies, revealed that musicians exhibited higher cognitive and sensory processing performance attributed in part to experience-based factors, focusing on three groups of young adult males (18-35 years of
age): percussionists ($l = 21$), vocalists ($m = 21$), and non-musician controls ($n = 18$). All control and experiment participants were vetted in advance for eligibility and where balance was assured in each test group in terms of age distribution and years of musical experience (at least 5 years), including the assignment of subgroups evenly distributed accounting for demonstrated sight reading and improvisational abilities.

Although the total sample was of modest size and not randomized, the Slater et al. (2017) study was of moderately high quality. The experimental method employed an electrophysiological procedure, a validated MATLAB toolbox courtesy of the Neuroscience Auditory Lab, and a statistical covariate analysis based on Kruskal–Wallis H tests. Slater et al. used the experimental tools and procedures to compare the multiple independent samples (percussionists, vocalists, and non-musicians; or sight readers, improvisors, and non-musicians) with post hoc pairwise Mann Whitney U testing. Strong group effects were measured ($-0.691 \leq r \leq 0.539$) in computing the KPMs.

Of primary interest was the Slater et al. (2017) hypothesis that cognitive functions were enhanced regardless of which instrument was played. Their study findings showed that percussionists demonstrated abilities to more precisely encode rapidly changing acoustic (speech) features compared to non-musicians. Furthermore, percussionists performed better than non-musicians and vocalists in attention to rhythm and timing and inhibitory control (reacting to audio/visual stimuli designed to interrupt or disrupt normal-flow cognitive processes).

Slater et al. (2017) suggest that percussionists have an inhibitory control advantage because their motor systems are more extensively engaged during practice—corroborating evidence supporting improved cognitive and motor control due to
overlapping neural circuitry. Vocalists on the other hand, exhibited better frequency selectivity (discriminating over the range of acoustical sound focusing on pitch and melody) with a stronger capacity to encode speech harmonics compared to non-musicians. These findings, not totally unexpected, suggest the benefit of music in interventions to heighten cognitive capacities. Simply stated, experience with music shapes the brain structurally and functionally.

Gordon, Cobb, and Balasubramaniam (2018) also examined how music affects the brain focusing on what regions of the brain were activated or stimulated. Gordon et al. used Gaussian-based activation likelihood estimation (ALE) to perform a meta-analysis of 42 neuroimaging studies on the effects of listening to music to determine how regions of the brain were activated. The quantitative study considered the listening habits of a wide array of musicians and non-musicians across the selected meta-studies. The action simulation for auditory prediction (ASAP) model, along with other extrapolative methods, were leveraged to measure the effects on the brain (Patel & Iversen, 2014). Whereas Slater et al. (2017) found correlations between active music playing and selected instruments and the cognitive and motor functions associated with the prefrontal cortex, Gordon et al. showed that passive music listening activated other regions of the brain. The regions were those associated with the supplementary and pre-supplementary motor areas including the right- and left-side lateral premotor cortex, right-side primary motor cortex, and the left-side cerebellum (which has a larger volume in musicians) used in music and rhythmic temporal perception.

Although Slater et al. (2017) were mainly interested in the structural effects on the brain, they cited neuroimaging evidence that suggest the style of playing also influences
the patterns of brain activation; for example, music improvisation results in lower
dorsolateral prefrontal activity but medial prefrontal and sensorimotor activity increases
when compared to sight reading. The demands of playing percussion instruments were
concluded to actively reinforce neural networks important for cognitive control by
synergizing (a) rhythm, (b) auditory processes, (c) coordinated motor movement, and (d)
cognitive development; or more generally, music experience and teaching music may
influence the crossover of musical expertise and skills to other domains such as
educational and clinical settings. Additional evidence of music’s influence on learning,
brain activity, and cognition can be found in studies on music listening.

Gordon et al. (2018) showed that when listening to music, the brain actively
engages with the audio stream by interpreting inherent periodicities or beat patterns of
sound. The parts of the brain important for timing and activity-relevant information or
action-based sequential structure are activated. The same processes occur in dance and
speech/conversation. Their study discovered a significant crossover or “resource
sharing” between the domains of cognitive, motor, and perceptual processes within the
various lobes and subregions of the brain. Gordon et al. concluded that plasticity-induced
changes in structural and functional neural connectivity, such as those exhibited by
musicians, can enable the sharing of neurocircuits used for action- and perception-based
information processing. Another perspective on the association between the art of music
and the science of sound is examined next.

Wu, Kendrick, Levitin, Li, and Yao (2015) quantitatively studied the intrinsic
synergies among musical pieces across different eras and genres vis-à-vis their
mathematical characteristics focusing on harmonics and consonant chords. The
harmonics and chord patterns provided important clues to localizing repeatable mathematical structures that could stimulate or influence human mood, behavior, emotions, and brain activity and whether the composers intended to achieve some desired effect along these dimensions. Wu et al. illustrated examples of applying science and mathematics to analyze musical structures. Geometric space models, graph theory, topology analysis, and compositional data analysis techniques were used (Burgoyne, Wild, & Fujinaga, 2013; Sethares & Budney, 2014; Tymoczko, 2006).

Additionally, Wu et al. (2015) noted that music inspired the Renaissance mathematician, astronomer, and astrologer Johannes Kepler to write “The Harmony of the World.” The piece effectively related the art of music to the science of sound and the natural world (Aiton, Duncan, & Field, 1997). Wu et al. hypothesized that consonance fluctuations in music followed a 1/f scale-free distribution specifically for melody, rhythm, pitch, human kinesiology, and electro-encephalic behavior—otherwise known as a “fractal” feature observed in music theory and the natural world (Mandelbrot, 1983).

Wu et al. (2015) paid special attention to the fluctuations in consonant and dissonant harmonic chord patterns centered on pitch, duration, and onset time (delays and intervals)—the basis of the circle of fifths in music theory. In conducting the study, they chose 1,191 movements from 568 compositions and by 20 composers (Mozart, Bach, Beethoven, Chopin, and others) across nine different music genres (prelude, waltz, fugue, ragtime, and so on) between the 16th century and 20th century. Wu et al. first computed a consonance rank (CR) metric to quantify the level of consonance. A detrended fluctuation analysis (DFA) and Wilcoxon signed rank test were then performed to analyze the nonlinear properties of the music structure and to validate the 1/f power
distribution relationship. They then used a two-tailed $t$-test to compare the properties by composer and music genre, lending to a high-quality study with appreciable effects size.

Based on the measured brain electrical activity, Wu et al. (2015) showed that humans “tune” in to the 1/f scale-free environmental harmonic noise signals (although they provided no indication of what specific regions of the brain were affected). Their study suggests that the 1/f distribution may be used to “bridge” musical harmony fluctuations with human emotions. The knowledge of this causal relationship may help to inform STEM experts of ways to positively enable STEM learning and engagement through the art form of music.

The above findings bear a closer examination regarding the ways that music can become part of the STEM learning experience. This can be achieved by either using music as a stimulus for learning or as an intellectual exercise in linking the art of music to the science and mathematics of sound. In the spirit of scientific inquiry and research, the knowledge garnered from the brain learning studies for STEM and non-STEM subjects can be used to inform scientists of new ways of imparting robust logic-emotion-creative artificial intelligence in machine learning algorithms and robotics applications (Eagleman, 2015, pp. 186-190).

Aligning these seemingly disparate fields in this way would serve to extend frames of thought, discourse, and research on the interconnectivity of the art and science domains for enhanced STEM learning, engagement, and understanding. The following section identifies the gaps in the vast body of research on STEM engagement per the findings above. The bridging of STEM learning and artificial intelligence is also discussed next.
Gaps in the Literature

The various factors contributing to the STEM gap are well documented in the literature and were reviewed in this chapter. The body of research is replete with information enabling a better understanding of the STEM gap problem and the practices and interventions used to narrow the gap. The literature review findings provided a foundation for the qualitative research design and the data gathering and analysis stages of the study as described in Chapters 3 and 4, respectively. The gathered data were analyzed and compared to the extant body of research to identify gaps in the literature. Chapter 5 discusses the broad implications of the study’s data findings and provides recommendations to the various stakeholders.

To begin, the literature review revealed gaps in the empirical studies on STEM engagement aimed at high school STEM seniors on the verge of graduating or upon entering college or the workforce and that compared their perspectives to those of educators. Although the present study and its results were confined to a specific research context, many of the findings pointed to a broader gap issue and lent to a series of recommendations as discussed in Chapter 5. The literature review findings on the various factors contributing to the STEM gap were largely corroborated by the data gathered in the study. In summary, the study concluded that for the research context chosen, the top several contributing factors were:

- The slow pace of institutional reforms and the delayed adoption of application- and outcome-based pedagogy in lieu of standards-competency-based learning that overemphasized high-stakes testing;
- Unfocused STEM outreach; and
• A lack of reliable, informed school career counseling or guidance due to the changing roles of counselors.

The findings showed that the Common Core State Standards often preempted the rollout of progressive STEM programs and curricula while reinforcing siloed STEM learning practices. A monolithic or one size fits all approach to STEM learning has proven futile and a detriment to STEM engagement. The standards-based testing was found to be a major “implicit” source of STEM disengagement because it constrained creative learning environments—a conclusion consistent with the literature review findings.

On the other hand, no explicit or blatant disparagement of the Common Core and its impact on STEM pedagogy or engagement was uncovered in the empirical literature. Furthermore, the literature review did not reveal any open findings on the impact of school counseling deficiencies as such on the STEM gap. The literature highlighted the importance of counseling as part of the STEM curation process but did not specifically identify school counseling as a STEM disengagement factor. Contrasting the data findings and the literature review findings on STEM outreach strategies revealed a gap, respectively, between targeted marketing to those with moderate-to-high STEM affinity versus appealing or outreaching to everyone regardless of their affinity.

Next, the implications on improving engagement outcomes by applying progressive interventions using a STEM theoretic framework were consistent between the gathered data and literature review findings. A theoretic framework such as the one adapted from the Lesh translation model (LTM) supports integrated, multidisciplinary STEM learning goals. Whereas the data findings showed that multiple trials to adapt a
theoretic STEM pedagogical framework were met with limited success, the literature did not elaborate on causality regarding STEM engagement using theoretic-based interventions except for a few seminal studies (Glancy & Moore, 2013; Lesh & Harel, 2003). However, another more significant gap emerged in the body of literature which is discussed as follows.

The qualitative data gathered revealed dual perspectives on the link between STEM learning and artificial intelligence (AI) that prompted a further examination. According to West (2018), the term *artificial intelligence* was coined by John McCarthy in the 1950s based fundamentally on the work of Alan Turing, a famed mathematician and cryptologist working for the Allied Forces during World War II. The term refers to machines that can think autonomously to gather data, build knowledge, and assist human decision-making and tasking. The qualitative data suggest that AI expert systems could significantly assist in STEM learning. STEM paves the way for futuristic AI research and development occupations that do not exist today. In this case, STEM pedagogy drives towards advancements in the field of AI research, but AI can also be used to effect positive change in STEM pedagogy.

In “teaching” AI systems—coding AI or domain knowledge into machines—a knowledge-based framework is constructed to capture and process “training” data. A data-to-decisions approach uses experiential-, behavioral-, and constraint-based algorithms, and where complex decision trees—cast as rules—predict a range of anticipated outcomes using probabilistic models. However, it is the unanticipated or improbable outcomes that give rise to concerns warranting further examination to enhance an understanding of the implications of AI expert systems in STEM.
Consider that the coding of AI systems and machines goes beyond mere *if-then-else* rules and logic-based algorithms—akin to STEM-side rules and constraints framing. As an understanding of AI evolves, human-based emotions and decision trees will be coded to progressively “temper” the logic and refine ways of mimicking the human brain’s reasoning and decision-making capacity—akin to non-STEM-side rules and constraints framing. Human decision-making simultaneously engages both sides of the brain informing AI researchers of methods to design robots that can logically reason and “express” emotion or “think” creatively. Although, an ethical imperative arises in the context of programming AI machines with a STEM versus a non-STEM framing.

The coding of AI systems can open a Pandora’s box—enabling negative societal biases towards sexuality and gender, race/ethnicity, religion, politics, and along other dimensions that could implicitly creep into AI state machines. The AI expert systems would, in effect, mirror those biases unless measures were taken to control, expunge, or process them out. A doomsday mindset sets in reminiscent of the sinister AI themes in the Home Box Office series *Westworld* heralding a bleak, dystopian future as AI “goes rogue” on humanity (Nolan & Joy, 2020).

Indeed, the looming dangers of AI have been foreshadowed in pop culture since the 1950s and 1960s when the modern computer first emerged. Some examples include *2001: A Space Odyssey* with the HAL 9000 AI computer; the M-5 multitronic unit—an AI computer—featured in an episode of the *Star Trek* television series that wreaked havoc on the crew of the U.S.S. Enterprise; the movies *I, Robot* and *The Terminator*; and countless other literary and cinematic pop culture references (Asimov, 1963; Clark, 1968;
Daly, Gibson, Hurd, & Cameron, 1984; Fontana & Lucas, 1968). Countless other examples of such foreshadowing of the dangers of AI can be cited.

To a certain extent, science fiction has become science fact. AI computers today can mimic the human’s ability to learn and acquire knowledge in direct proportion to their capacity for gaining power and control and therein lies the issue with AI. Notwithstanding, a positive side to AI exists. Indeed, an extensive body of empirical research along with literary and anecdotal storytelling exists on human and machine learning and the ethical implications of AI expert systems. However, the research corpus was void on studies that addressed AI’s influence on STEM pedagogy—the next point of departure.

The emergent AI theme inspired a deeper examination of the relevant issues on STEM learning within the intended scope of the study. The examination converged on the converse perspective where AI drives advancements in STEM pedagogy and content delivery. This perspective highlighted a major gap in the literature opening avenues for future research. For instance, an AI-assisted approach can be used to perform data analytics on the myriad factors influencing STEM learning (inputs) to craft an optimal STEM program (output) that best meets an institution’s specific needs (objective function) for narrowing STEM gaps (outcome). Clearly, important implications arise for STEM learning programs, interventions, and developing evidence-based reforms.

For instance, motivational learning engagement viewed through the lenses of pedagogical agents and learning frameworks was identified in the literature; however, the documented strategies were not explicit to STEM and were only loosely framed in an AI context. Furthermore, several of the studies sparsely alluded to AI-assisted pedagogy,
but none of them were directly applied to STEM learning. The literature review also revealed that experiential STEM learning was on the fringes of AI research at best; the contexts and interventions were not necessarily aligned with the goals of enhancing STEM pedagogical engagement or STEM curriculum policy reform payoffs. Nonetheless, several of the studies can inform the development of AI-assisted technologies for increasing STEM engagement as follows.

Bull and Kay (2007) suggest an open or adaptive framework to enhance learning engagement goals that is discipline-agnostic and could be AI-assisted. They designed an open framework with a metacognitive foundation where the learner has a significant stake in the learning process and would be motivated to help drive the process for self-benefit and to help others with common affinities or interests. On the other hand, Baylor and Kim (2005) used pedagogical agents to validate the impact of human-computer interactions and human-human interactions to design and empirically validate a system that could aid in instructional learning. Conceivably, such pedagogical agents could be software-based intelligent agents. The direct involvement, interaction, experience, and feedback of the learners as research participants can help shape the intelligent frameworks and pedagogical aids. Kim, Belland, and Walker (2018) pointed to the use of AI in automated content analysis to interpret the articulated thoughts of learners for computer-based scaffolding in STEM problem-based learning scenarios.

Al Salami, Makela, and de Miranda (2017) and Chai, Jong, Yin, Chen, and Zhou (2019) claimed that extant research on teacher professional development in STEM was limited, thus paving the way for new STEM pedagogical expert system frameworks to fill the gap. Chai et al. reported on an integrative STEM pedagogical approach that
accounted for the diverse content and multidimensional knowledge that today’s STEM teachers must possess and that could assist in STEM teacher effectiveness for improved outcomes. Further, Chai et al. employed the Technological Pedagogical Content Knowledge (TPACK) framework to develop a survey that measured teachers’ self-efficacies across multiple dimensions of STEM knowledge. The framework facilitated the overlap of pedagogical content knowledge (PCK), technological content knowledge (TCK), and contextual learning (Chai et al., 2019; Shulman, 1986). The TPACK framework could be used to inform the design of an intervention using AI expert systems.

Avramides, Hunter, Oliver, and Luckin (2015) examined how models of STEM teachers as initiators of change, using evidence-based inquiry, could influence top-down processes towards reforms. A cross-curricular STEM project with 57 educators was designed that employed Google Forms to conduct an inquiry and assessment of teachers’ use of tools and communication and how these impacted their learning of new tools. A Teacher Inquiry into Student Learning (TISL) approach was used based on the Teacher Design Research (TDR) theoretic framework (Bannan-Ritland, 2008). Once again, the knowledge gained from the application of such framework-theoretic models can inform the design of AI-assisted approaches. Examining the STEM gap problem through the lens of AI-assisted framing or AI rezoning has significant implications on STEM pedagogy and learning engagement which are further discussed in Chapter 5.

Indeed, precedents exist on the use of AI to steer desired outcomes across a variety of fields and applications from finance to medicine to entertainment. For example, IBM’s Watson computer—a machine learning system—is being used in virtual medicine (telemedicine, data analytics) and healthcare applications (telehealth
monitoring) to remotely treat patients across a spectrum of infirmities (IBM, 2020). The Watson computer has also been used to compete against human contestants in the television game show Jeopardy! in 2011 and was used to craft fine dining menus and unique flavored dishes to meet specific dietary and nutritional needs (Allen, 2018; Best, 2013; Pinel, 2015). Its predecessor, IBM’s Deep Blue, mastered the art of chess and mercilessly defeated the chess champion Gary Kasparov over 20 years ago (Levy, 2017). Clearly, AI cognitive computing applications can be used to produce optimal outputs for a range of applications. This implication points to the development of strategies to leverage AI for the benefit of STEM pedagogy and engagement and to significantly add to the body of research on the topic.

A thorough literature review did not uncover any significant findings on the use of AI expert systems in STEM learning from the standpoint of curriculum and lesson plan development that addressed specific institutional needs to narrow STEM gaps. The LTM theory provides a basis for a STEM or STEAM theoretic framework that can leverage AI for this purpose as will be discussed in Chapter 5. A useful association to consider is, *pure logic and reason* is to STEM as *logic tempered by emotion and creativity* is to STEAM, thus underscoring the advantage of a multidisciplinary strategy in AI that is not exclusive to the STEM subjects, and which has been elusive as a readily instantiable process to date. Scientists can easily program logic and reason, but programming reason tempered by emotion and creativity continues to be a more challenging endeavor.

Applying AI in the context of a conceptual STEAM theoretic framework “rezones” the STEM gap issue and is a candidate for qualitative grounded theory research to develop a revolutionary STEM engagement strategy. Randomized, experimental
studies could also help isolate which AI-assisted STEM strategies or models work best to enhance progressive STEM pedagogical outcomes. The findings could inform teacher preparedness programs in higher education including school curricula to fill STEM learning gaps. This begs the question, “Could AI expert systems be used to craft an optimal, custom-fit STEM curriculum and delivery method for virtually any institutional program and setting?” A comprehensive chapter summary is provided next which synthesizes the various research studies, literature findings, and expert viewpoints across the subject areas addressed above. The summary includes the key findings and tenets borne out by the literature review, providing for a collective understanding of the STEM gap problem and potential interventive methods for fostering engagement.

**Chapter Summary**

Chapter 1 presented evidence that showed the US performs poorly in STEM education despite efforts to expand academic STEM programs over the past 20 years (Gonzalez & Kuenzi, 2012). The number of unfilled STEM jobs and the pursuit of STEM fields in higher education and the labor force continue to increase. The STEM engagement gaps are worsening contributing to greater STEM pipeline leakage and a consequent widening of the STEM gap. The root of the problem appears to trace back to the efficacy and quality of STEM education today and the effectiveness of ongoing efforts to engage and retain students in the STEM pipeline or the lack of effective strategies thereof.

This chapter examined the current state of STEM pedagogy highlighting studies that addressed experimental interventions or institutional reforms designed to increase STEM engagement and reduce the gap. The research on the causes for the STEM gap
over the past 10 years points to the growing importance of new, pedagogic interventions. The interventions employed variants of integrated, interdisciplinary active learning in place of traditional, siloed STEM learning protocols (Glancy & Moore, 2013).

The Chapter 2 literature review delved deeper into the salient issues that challenge STEM engagement and persistence centering on STEM pedagogy, academic curricula, learning environment, and content delivery. Throughout the empirical studies reviewed in Chapter 2, a set of common themes emerged. The themes were used to establish a priori codes that were used as waypoints to facilitate the data gathering portion of the study as discussed in Chapters 3 and 4.

The themes from the highest-quality studies encompassed a range of considerations on the factors affecting STEM engagement and persistence. The themes included: (a) the importance of small-group collaborative activity (Sriraman & Lesh, 2007; Springer & Stanne, 1999); (b) a high degree of teacher-student interactions, trust in educators, and teachers who inspire and motivate students (Jackson et al., 2014); (c) nurturing interactive, immersive learning with real-world contexts (Allen et al., 2016; Christensen et al., 2015); (d) the benefits of integrated, interdisciplinary learning strategies (Belland et al., 2015; Brown, 2012; Gottfried, 2015; Kertil & Gurel, 2016; Kezar & Gehrke, 2017; Sanders, 2012; Sriraman & Lesh, 2007; Stage & Kinzie, 2009); (e) the advantages of using technology-based, multimedia, and multimodal learning environments (Akyurek & Afacan, 2013; Bruce-Davis et al., 2014; Capraro et al., 2016; Connors-Kellgren et al., 2016; Duman, 2010; Gabriel, 1999; Mullender-Wijnsma et al., 2015; Proudfoot & Kebritchi, 2017); (f) fostering self-efficacy and confidence for positive STEM outcomes (Wilson et al., 2015); (g) educator and institutional scaffolding
for improved outcomes (Belland et al., 2015; Fan & Yu, 2017; Mativo et al., 2013; Whalen & Shelley, 2010); (h) exploiting interdisciplinary connections through mathematics (Hutto et al., 2015; Korpershoek et al., 2011; Moakler & Kim, 2014; Stieff & Uttal, 2015; Tobias, 2014; von Károlyi, 2013; White et al., 2012); and (i) non-STEM influencers. Certain of the studies raised thoughtful, profound questions and revealed subtle touchpoints on the nature of the STEM gap problem.

In particular, the high-quality meta-study by Springer and Stanne (1999) provided a foundation for the literature review that emphasized the importance of small group collaborative learning on STEM engagement. Brown (2012) further cited an overwhelming number of studies on the critical importance of integrative, interdisciplinary STEM education and small-group collaboration. Kezar and Gehrke (2017) recommended socializing new practices aimed at interdisciplinary learning. Stage and Kinzie (2009) identified six dimensions of effective STEM learning reform for increased STEM persistence and student satisfaction that encompassed trusted faculty, collaborative learning, active learning, real-world contexts, and interdisciplinary themes. Wilson et al. (2015) on the other hand highlighted the importance of cultivating a sense of belonging and nurturing self-efficacy in STEM learning drawing on students’ satisfaction and academic “safety” themes.

Jackson et al. (2014) identified unprepared teachers, poor motivation, and high school STEM-education gaps as the main predictors of STEM disengagement. They suggest a nurturing STEM learning environment that actively engages students, encourages trust and openness, challenges students, and inspires creative problem solving as ingredients critical to STEM persistence. Ernst et al. (2018) addressed STEM
teachers’ level of satisfaction and willingness to promote creative STEM activities and noted that technology educators have the greatest chance of influencing STEM reforms. Consistent with the study by Ernst et al., Kezar and Gehrke (2017) suggest that academic institutions establish policies and rewards to motivate faculty towards hastening reforms.

Connors-Kellgren et al. (2016) showed how students’ STEM engagement can increase by implementing technology-enhanced STEM curricula. The study by Proudfoot and Kebritchi (2017) found that SBL coupled with an eLearning approach can lead to increased learner engagement. Capraro et al. (2016) provided compelling evidence of PBL’s efficacy in improving student STEM achievement for high-fidelity PBL implementations in urban classrooms. Bruce-Davis et al. (2014) also cited PBL as an effective STEM engagement protocol, thus supporting the claims of Capraro et al. in the urban PBL study.

The literature review on integrated, interdisciplinary active learning approaches to STEM pedagogy examined more deeply how the individual STEM disciplines related to each other and how one achieves an understanding of those relationships. It also introduced the dimensions of active and applied group learning tied to real-world contexts, experiences, and concrete manipulatives. Students, teachers, and academic institutions supported by districts, state education boards, and legislators are at the nexus of assuring successful implementations and positive outcomes.

Sriraman and Lesh (2007) reinforced the notion of teamwork and structural relationships in STEM learning using scaffolding to establish a framework for an interactive, immersive intervention. Belland et al. (2015) further showed the utility of interdisciplinary interventions using computer-based scaffolding and multimedia tools to
enrich students’ experiences and problem-solving skills. The findings of Fan and Yu (2017) and Mativo et al. (2013) were consistent with the meta-study by Belland et al. on the efficacy of scaffolding, but across different integrative and disciplinary dimensions. Whalen and Shelley (2010) identified the predictors of student STEM achievement and persistence and highlighted the importance of educator or institutional support which were consonant with the findings of Belland et al. and Mativo et al.

Gottfried (2015) showed that a positive correlation existed between introducing applied STEM courses into high school curricula and reinforced STEM persistence. Roehrig et al. (2012) demonstrated an increase in students’ STEM learning performance by integrating STEM lesson plans in secondary schools and connecting them to other disciplinary learning activities. Gottfried’s findings agreed with those of Belland et al. (2015), Mativo et al. (2013), Roehrig et al., and Whalen and Shelley (2010) on the need for best practices, interventions, and reforms for sustained institutional scaffolding at multiple levels. Kertil and Gurel (2016) further conceptualized an integrative STEM pedagogical approach drawing on the findings of Roehrig et al. and focusing on content and context integration. These sources represented some of the highest quality studies.

Sanders (2012) underscored the significance of integrative STEM learning and emphasized mathematics to solve real-world problems as a best practice. A complementary view by Christensen et al. (2015) was that interactive learning with real-world contexts tended to evoke positive STEM interests. The Christensen et al. and Sanders studies were consistent with the findings of Belland et al. (2015), Gottfried (2015), Mativo et al. (2013), and Roehrig et al. (2012) on the importance of applied, interactive learning and content delivery. Allen et al. (2016) further emphasized the need
for an adaptive STEM learning approach that was built upon STEM-related conceptual
development, inquiry, and practical or real-world contexts.

Flogie and Aberšek (2015) and Henrkisen et al. (2015) approached STEM
learning from the perspectives of neuroscience, cognitive science, and education to
explain the advantages of combining disciplines for deep learning. Flogie and Aberšek
viewed the concept from a fundamental transdisciplinary learning approach. On the other
hand, Henrkisen et al. introduced synthesis in transdisciplinary learning that has
theoretical and practical value for STEM pedagogy using technology, mathematics, and
digital tools for synthesis.

Mathematics plays an important role in connecting STEM and non-STEM
domains. It enables an understanding of the relationships between seemingly disparate
disciplines to craft STEM curricula that are highly diverse, engaging, and appealing.
Moyer et al. (2018) and Tobias (2014) highlighted the diversity and creativity in
engaging with music via digital media, technology, and math that allowed one to create
music experimentally, theoretically, and mathematically as a STEM engagement device.
Korpershoek et al. (2011) and Moakler and Kim (2014) on the other hand emphasized the
relative importance of math aptitude, math confidence, and achievement motivation on
attitudes and performance towards advanced STEM learning.

Hutto et al. (2015), Stieff and Uttal (2015), and von Károlyi (2013) showed that
there were strong relationships between learning math, learning sports, spatial training,
mental rotation, and STEM achievement. DiTullio (2018), Donnelly and Lambourne
and Ratey (2009), and Shephard and Trudeau (2005) provided corroborative evidence of the
strong relationship between learning and kinesiology and increased math and reading performance coincident with physical activity. The findings lent to an understanding of STEM deep learning and reinforcement learning and how the human brain processes knowledge and establishes relationships for lasting effect. White et al. (2012) showed that concept generation (brainstorming) was highly influenced by knowledge and skills in math. Sax et al. (2015) found that lower math confidence generally deterred STEM pursuits whereas Peters et al. (2017) concluded that greater numeracy or mathematical ability may make individuals more apt to pursue STEM careers.

Chapter 2 also highlighted the various aspects of the brain-math-music synergy and its positive effect on STEM learning and engagement. Daugherty (2013) showed that science Nobel laureates were four times as likely to be musicians. Hummell (2014) quoted Albert Einstein as having said, “Look deep into nature, and then you will understand everything better” (p. 32). Gordon et al. (2018) and Slater et al. (2017) described the synergy between the art of music and the science of sound on brain learning and concluded that experience with music can shape the brain structurally and functionally. Gordon et al. further studied what parts of the brain were affected by listening to music and how ultimately music may influence learning and engagement in the field of mathematics.

Wu et al. (2015) suggested that an understanding of the harmonic spectral distributions found in music may be used to “bridge” musical harmony fluctuations with human emotions; understanding this relationship may help inform STEM experts of ways to enhance STEM learning and particularly improve math engagement through music. Wynn and Harris (2013) believed that a reciprocal benefit arises by joining artists
Payton et al. (2017) demonstrated how dance art was related to interdisciplinary STEM problem-solving, collaboration, and critical thinking tasks. Grant and Patterson (2016) similarly suggest that the arts animated learning via an experiential process that stimulates creativity and critical thinking, which are equally valued in STEM pedagogy. Carrese, Kim, and Creeden (2013) stressed the importance of interdisciplinary learning in STEM that embraced the humanities. DiTullio (2018), Eagleman (2015), Kelly (2012), Perry (2002), and Reimer (2004) underscored the importance of stimulating brain activity and brain development through multidisciplinary learning and experiences. They cited how environmental stimuli can directly impact the emotion and values-based reward centers of the brain that in turn increases learning capacity.

The literature review revealed gaps in the empirical studies on STEM engagement for high school seniors on the verge of graduating or upon entering college or the workforce and that compared their perspectives to those of educators. The testing standard associated with the Common Core was deemed a major “implicit” source of STEM disengagement because it constrained attempts at implementing creative learning programs and initiatives. However, no explicit or blatant disparagements of the Common Core and its impact on STEM pedagogy or engagement were uncovered in the empirical literature.

Furthermore, the literature review did not reveal any open findings on the impact of school counseling deficiencies specifically regarding STEM. The literature highlighted the importance of counseling in curating an ecosystem that is conducive to STEM interests but did not specifically identify school counseling as a factor in STEM education.
disengagement. Contrasting the data findings and the literature review findings on STEM outreach strategies revealed a gap, respectively, between targeted marketing to those with moderate-to-high STEM affinity versus appealing to everyone regardless of STEM affinity.

The qualitative data gathered revealed perspectives on the link between STEM learning and artificial intelligence (AI) that prompted a further examination focused on understanding how AI could drive advancements in STEM pedagogy and content delivery. However, the literature review did not uncover any significant findings on the use of AI expert systems in STEM learning from the standpoint of curriculum and lesson plan development that addressed specific institutional needs aimed at narrowing STEM gaps. Sriraman and Lesh (2007) advanced the LTM theory as a STEM theoretic framework that could be used for this purpose. The approach has important implications on STEM learning programs, interventions, and developing evidence-based reforms.

Motivational learning engagement viewed through the lenses of pedagogical agents and learning frameworks was identified in the literature; however, the documented strategies were not explicit to STEM and were only loosely framed in an AI context. Furthermore, several of the studies sparsely alluded to AI-assisted pedagogy, but none of them were directly applied to STEM learning. The literature review also revealed that experiential STEM learning was on the fringes of AI research at best; the contexts and interventions were not necessarily aligned with the goals of enhancing STEM pedagogical engagement or STEM curriculum policy reform. Nonetheless, several of the studies provided useful insights that could help inform the development of AI-assisted technologies for increasing STEM engagement.
Bull and Kay (2007) suggest an open or adaptive learning framework that is discipline-agnostic and could be AI-assisted to enhance learning engagement goals. Baylor and Kim (2005) used pedagogical agents to validate the impact of human-computer interactions and human-human interactions to design and empirically validate a system that could aid in instructional learning. Kim, Belland, and Walker (2018) pointed to the use of AI in automated content analysis to interpret the articulated thoughts of learners for computer-based scaffolding in STEM problem-based learning. Chai et al. (2019) reported on an integrative STEM pedagogical approach that accounted for the diverse content and multidimensional knowledge that today’s STEM teachers must possess and that could assist in STEM teacher effectiveness for improved outcomes.

The study by Chai et al. (2019) adopted the Technological Pedagogical Content Knowledge (TPACK) framework to measure teachers’ self-efficacies across the multiple dimensions of STEM knowledge. Avramides, Hunter, Oliver, and Luckin (2015) additionally examined how models of STEM teachers as initiators of change, using evidence-based inquiry, could influence top-down processes towards implementing reforms. Their study adapted the Teacher Design Research (TDR) theoretic framework (Bannan-Ritland, 2008). The knowledge gained from the use of such framework-theoretic models can certainly inform the design of AI-assisted approaches. Examining the STEM gap problem through the lens of AI-assisted framing or AI rezoning has significant implications on STEM pedagogy and learning engagement.

Applying AI in the context of a conceptual STEAM theoretic framework is a candidate for qualitative grounded theory research to develop a revolutionary STEM engagement strategy. Randomized, experimental studies could also help isolate which
AI-assisted STEM strategies or models work best to enhance progressive STEM pedagogical outcomes. The findings could inform teacher preparedness programs in higher education including school curricula to fill STEM learning gaps.

Further consideration will be given to examining the role of non-STEM factors for a comprehensive study. The next chapter will shift to a discussion of a qualitative case study design that was used to characterize the context of the high school STEM problem and its inherent dynamics, including human perspectives and lived experiences in accordance with proven, recommended case study methods (Creswell, 2007; Flick, 2014; Preskill & Russ-Eft, 2016). The research questions and data collection methods employed were aligned with the case study method as discussed next.
Chapter 3: Research Design Methodology

Introduction

The chapter describes the research design, the rationale for the research model selected, the research context and the participants including the selection and sampling criteria employed, the data collection instrument, and the data collection and analysis procedures for the study. In selecting the research model, the first imperative was to consider an academic site with an active STEM program that allowed convenient access to students and educators in the program who had frontline exposure to STEM pedagogical practice and engagement issues. The second imperative was to develop an understanding of STEM pedagogy to identify up close and personal, rather than through a remote survey, the factors that impinged on STEM engagement/persistence and that in one way or another contributed to the STEM gap. The third imperative was to be able to conduct a thorough study within realistic timing. After reviewing several methods, the qualitative, single case study research method was selected.

The STEM gap has been a topic of growing national and global concern with significant leadership and social justice implications. America’s role as a global leader in technology, education, and innovation has eroded over recent years. The nation’s technological, economic, and political resiliency has been tested. Technological resilience depends on an able and agile STEM workforce that can bring human and intellectual capital to bear to solve problems for the benefit of humanity. Gonzalez and Kuenzi (2012) reported a steady decline in STEM persistence and an increase in STEM
pipeline leakage. The International Activities Program National Center for Education Statistics (2015) and the Pew Research Center (2017) presented further compelling evidence of the widening gaps in STEM engagement. The findings speak to the growing concern over America’s ability to sustain technological resilience and the importance of its “STEM resources” for that purpose.

The study sought to fill a gap in our understanding of the factors that affected STEM engagement and persistence between 12th grade and upon entering college or the workforce. The vast body of research lacked empirical studies and evidence that addressed the issue during the transition period. Known is that a significant drop in students pursuing STEM majors and STEM careers has occurred upon/after high school graduation that has led to a growing number of STEM job vacancies over time (Drozd et al., 2017; Gonzalez & Kuenzi, 2012; Lazio & Ford, 2019; National Science Foundation, 2014; White House, 2009). High school is the “last stop” in grooming true and meaningful interest in STEM and feeding the STEM workforce pipeline. The study examined STEM engagement from the perspectives of students and educators during the last year of high school to reveal ways of closing the STEM gap.

The research design methodology examined a case study of STEM pedagogic practices in one Central New York State (CNY) high school to identify gaps that impacted senior student engagement outcomes. Post-2007 leadership and organizational interventions were explored that were designed to reinforce STEM engagement and persistence through progressive STEM pedagogy such as the application of integrated, interdisciplinary, active learning protocols. The impact of interventions and learning protocols on STEM engagement was of main interest with the focus on seniors who
planned to enroll as STEM majors in college or enter the STEM workforce. The research attempted to raise awareness of the factors affecting STEM education outcomes and explored new approaches for increasing STEM engagement/persistence and narrowing the gap. The research emphasized pedagogic themes and to what degree interdisciplinary synergies were operationalized via integrated, multidisciplinary STEM learning frameworks. Shared mathematical frameworks between STEM and non-STEM disciplines that emphasized music as an engagement device were also of interest.

The case study research focused on a selected CNY high school with an active STEM program that was held during the normal school day or optionally as a separate cocurricular (after-school) activity. The research attempted to identify the predominant strengths, weaknesses, and areas of improvement in STEM pedagogy and learning environments to identify ways of mitigating STEM attrition upon/after high school graduation. A focus group instrument using semi-structured and open-ended focus group questions aligned with the research questions was used to facilitate the data collection and analysis to produce the study findings. The research questions are reviewed next.

**Research questions.** The research questions for the study aligned with the case study research method. A qualitative, single case study design was appropriate for the research because it attempted to understand a context of the subject (STEM pedagogy at a selected CNY high school) and its inherent dynamics, including human perspectives and participants’ experiences (Creswell, 2007; Flick, 2014; Preskill & Russ-Eft, 2016). The research questions are reiterated as follows:
1. From the student’s perspective, how does participation in a STEM learning program stimulate or deter interest in pursuing a STEM major in college or as a career choice?

2. From the perspective of the educator, how do current STEM programs contribute to or detract from STEM persistence after high school, during college, and as a career choice?

3. From the standpoint of students and educators, why might STEM persistence or sustained STEM interest upon/after high school graduation be on the decline?

4. From the perspective of students and educators, how can interest in pursuing a STEM major in college or a STEM career be increased?

The research questions were directed at high school seniors participating in a STEM program and high school STEM educators. A focus group protocol was designed to answer the research questions via a crosswalk scheme (Caplan, 2003). The research questions were parsed according to student and teacher participant groups as described in Appendices A and B, respectively. Additional rationale for the case study method is provided next addressing the four key coordinates of research participants, research method and activities, timeframe, and location.

**Description of overall research methodology design.** Bromley (1986) and Yin (2014) stated that case study research attempts to systematically derive an in-depth understanding of one or a few numbers of “cases” (“units of analysis”) in natural, real-world settings. Case studies typically involve a detailed, qualitative investigation of one or more individuals, group(s), systems or processes, organizations (an academic
institution), settings or locations (a school classroom), or an event (Flick, 2014; Mertens & Wilson, 2012). Alternatively, case study research allows for a detailed, holistic examination of one or more instances of a phenomenon bounded in context, time, or place accompanied by rich descriptors (Edwards, 1998; Gliner, Morgan, & Leech, 2017).

Gliner et al. (2017), Stake (1994), and Stake (1995) recommended that case study research was suitable for institutional contexts such as educational settings by facilitating subjective interpretations that draw on personal experiences. Merriam (2001), Stake (2005), and Yin (2014) further indicated that the case study design aligned well with collecting data from a diverse group of participants, allowing for the various perspectives of the group to be heard; collectively, they suggested various typologies useful in characterizing case studies and enabling the generalization of findings in other settings, thus establishing a firm foundation for the present case study research. However, the present research did not attempt to generalize the findings of the selected case study to other cases, sites, or populations per recommended methods and accepted protocols (Brinkmann and Kvale, 2015).

A holistic, single-case study design was used that focused on one instance of an active STEM-type program at a selected research site. The design employed a particularistic, explanatory, and collective case study research method allowing for analytical generalization within the scope and research context of the study (Merriam, 2001; Stake, 2005). An independent, in-depth examination of a single case of STEM pedagogy in a selected high school was conducted emphasizing learners, educators, and personal development experiences as the bounded phenomenon of interest. The research context for the case study research is described next.


**Research Context**

The case study was performed onsite at a suburban public high school in the CNY region that had implemented programs to increase STEM retention and included non-STEM electives such as music, art and humanities, history, English, and other non-STEM subjects. The key criterion in selecting the case study research context was a high school that put into practice the New York State Board of Regents NYSED Next Generation Science Standards as the basis of an active STEM program and that had maker spaces or equivalent facilities to conduct STEM activities (NGSS, 2018; NGSS Lead States, 2013; NYSED, 2019). The second criterion was *convenience* in leveraging already-established relationships with high school and other institutional stakeholders. East Syracuse-Minoa (ESM) High School and its Spartan Academy STEM Program met the requirements for the case study.

A cocurricular STEM-type program that applied progressive models like project-based immersion learning was considered if such a program was active and was in-school or classroom-based at the time of the study. The natural settings allowed for environmental factors, social or interpersonal dynamics, and situational demographics to be carefully studied. The criteria for selecting research participants are discussed next.

**Research Participants**

Nonprobability *purposeful sampling* is particularly useful in case study research (Gliner et al., 2017; Mertens & Wilson, 2012). This sampling method was used for the present study. Gliner et al. stated that purposeful sampling can apply to both the case and the sampling of information from within the case. In purposeful sampling, specific criteria and rationale are established to select the case and participants that are
information-rich sources. The selection strategy can vary from *maximum variation sampling* (eliciting multiple perspectives) to *extreme case sampling* (identifying highly problematic or elucidative cases) in matching participants to the established criteria.

Purposeful sampling, along practicing the NYSED Next Generation Science Standards, was used to guide the process of selecting the research context to conduct the case study. Using the criterion-based sampling, ESM High School was selected for the case study research because it had implemented a progressive STEM program in accordance with the science standards along with industry and university curricula (Project Lead the Way, 2019; Rochester Institute of Technology, 2019; Rowley, 2012). The school included arts and humanities disciplines (music, music theory, and other non-STEM subjects) as electives in their STEM program offerings. Table 3.1 summarizes ESM High School’s situational demographics and other descriptors considered important to the research (U.S. News & World Report, 2018a, 2018b, 2018c, 2018d).

Table 3.1

**ESM High School Institutional Demographics**

<table>
<thead>
<tr>
<th>Name</th>
<th>Total Enrollment</th>
<th>% Minority Enrollment</th>
<th>% Total Economically Disadvantaged</th>
<th>No. Full-time Teachers</th>
<th>No. 12th Graders</th>
<th>Gender Breakdown (%M/%F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESM</td>
<td>1,045</td>
<td>13%</td>
<td>37%</td>
<td>97</td>
<td>255</td>
<td>53%/47%</td>
</tr>
</tbody>
</table>

A purposeful, maximum variation sampling strategy was used to recruit a representative group of ESM student participants ($N_S \sim 20$ total) and educators ($N_E = \text{five to ten total}$) for the study across the high school’s STEM program. Purposeful, maximum variation sampling sought to encompass participants who represented a broad range of pro/con viewpoints regarding STEM pedagogy; furthermore, the sampling method helped to ensure that diverse perspectives were offered over multiple dimensions of STEM
learning and engagement including progressive and sometimes extreme viewpoints. The purposeful sampling targeted students who participated in ESM’s STEM program during at least the period of the study or who were openly STEM-disposed and included STEM educators.

Invitations were extended to the sample population to participate in the study mainly through focus groups. Remote observations were made from a researcher perspective to qualitatively assess the level of student interaction and engagement during the in-school focus group sessions. Although the case study research emphasized the focus group protocol, provisions were made for a limited number of post focus group one-on-one (individual) interviews, as necessary, aimed at STEM students who exhibited either very high (enthusiastic) or very low (apathetic) engagement during the term of the study. The two-step sampling procedure that was used is further described next.

Flick (2014) and Mertens and Wilson (2012) provided a framework for selecting participants in qualitative case study research using focus groups followed by a one-on-one interview protocol. Participatory inquiry, in the form of group interview sessions, stressed a small working team and whole community for the focus group meetings. Homogeneous focus groups comprised solely of students were limited to up to three groups (depending on the total number of students participating and evenly grouping them) for each major audience segment consisting of six to ten participants; the focus group protocol employed a nondirective, conceptual, and conversational interview style designed to encourage or elicit a diversity of perspectives (Brinkman & Kvale, 2015).

The focus groups involved both STEM students and educators whereas the optional one-on-one interviews were strictly limited to students. The STEM educators
and selected students from the joint sample population identified in the study were recruited to participate in the focus group sessions using purposeful sampling. The selected one-on-one interviews with the students were contingent on observing certain responses or reactions that surfaced during the focus group sessions warranting follow-up investigations.

For the individual student interviews, purposeful sampling was employed to target participants using the qualitative variation criterion of high, moderate, and low engagement as displayed by students during the focus group sessions and across specific categories for each major audience of interest. Student participants who expressed strong or even wavering opinions during the focus group sessions, were considered for an invitation to participate in a one-on-one interview that emphasized the following categories of interest: (a) general (all-inclusive) STEM program efficacy, (b) integrated STEM efficacy, (c) integrated STEM plus music, and (d) synergies between mathematics and music. The indicator of engagement was determined per independent, nonintrusive, or passive observations from the researcher’s perspective during the focus group stage.

The representative student population forming the pool of participants in the study was identified with the help of high school administrators and officials. The school administrators were requested to provide contact information on the representative student population that remained anonymous. The eligible students (18 years or older participating in the school’s STEM program or related activity) were recruited for the study via electronic means and/or in person with the aid of their STEM teachers and school officials. Once again, purposeful sampling was used to assure that study participants were STEM-oriented seniors of desired age plus STEM teachers. To
reiterate, the focus group participants were drawn from the whole groups using purposeful, maximum variation sampling. The individual interview participants were drawn from the whole groups based on observations made by the researcher during the focus group sessions (note: although provisions were made to conduct individual student interviews, none were actually conducted for two reasons: first, there were no unusual or extreme reactions by any of the student participants during the focus group sessions that warranted follow-up interviews; and second, time and schedule limited access to the students for follow-up interviews).

In the case of the students, permissions and nondisclosures for the conduct of the interviews were coordinated in advance and obtained in writing. The interview sessions were conducted under academic staff supervision when possible. Furthermore, because the research was considered passive (nonintrusive), benign, and of low risk, none of the participants were reimbursed in any manner. However, amenities in the form of light snacks and nonalcoholic beverages were provided as an appreciative gesture for the participants’ time in the study. The data gathering instruments are discussed next.

**Instruments Used in the Data Collection**

Qualitative case study data collection involved developing a checklist to identify and gather data sources. For the case study research, which emphasized the focus group protocol, the primary data sources included: session recordings and interview transcripts; oral or audio interviews; notes or narratives from the researcher’s perspective; institutional archival records on scholastic STEM programs; in-school STEM program brochures; and electronic minutes from organization/group meetings or planning sessions related to the school’s STEM activities when available. The main sources of data were
generated from direct observations of participant reactions during the focus group process, remote observations from a researcher perspective of student engagement during STEM-related activities (as practicable), raw field notes, self-reports, and other documents about the case study and settings for a bounded timeframe (Brinkman & Kvale, 2015). Recording devices were used to prepare transcripts when conducting open-ended focus groups and interviews with the proper consent forms executed in advance.

A crosswalk scheme was used where the research questions and bounded phenomenon drove the inquiry and data collection process to address the literature review sections and later chapter research and development (Caplan, 2003). The combined use of video- and audio-recorded focus group sessions, one-on-one interviews (not conducted, but full anonymity would have been assured), transcripts, and researcher field notes (based on direct observations of participant reactions during the focus group and individual interviews) comprised the data collection instruments used in answering the research questions. The stepwise procedures for data collection are described next.

**Procedures for data collection.** Advance preparation was needed to handle the large amounts of qualitative data in a documented and systematic fashion. This included the preparation of databases using a Computer Assisted Qualitative Data Analysis Software (CAQDAS) tool like NVivo, Atlas, or an equivalent utility to assist with categorizing, sorting, storing, and retrieving data for iterative interpretations (Atlas.ti, 2019; Saldana, 2015). Although Atlas was used during the early stages of the study, manual methods using Microsoft Excel and Word were found to be of more utility and facilitated a less formal manipulation and iterative reduction of the research data collected. The inquiry-driven data collection procedure unfolded as follows.
First, the proper consent/permission forms were coordinated in advance to facilitate the data gathering. Contingent on receiving approval from St. John Fisher College’s Institutional Review Board (IRB) and once all explanatory, permission, and advisory documentation were prepared, steps were taken to coordinate with the school organizational officials and administrators to arrange access and schedule visits to the research site. Early requests were submitted for the school officials to obtain lists of eligible STEM-oriented students who were at least 18 years of age at the time of the study, who participated in a scholastic and/or cocurricular STEM program or activity in their senior year, and who anticipated pursuing a STEM major in college or as a career. The lists included names and email addresses that were not made available to the researcher in advance for privacy reasons. Lists of high school STEM educators and cocurricular STEM instructors were also gathered, as applicable, but not disclosed in advance to the researcher.

Additionally, prior documented findings on STEM programs at the selected research site were sought and collected. This step helped to establish baselines for the single-case study and lent valuable insights into the nature of the STEM gaps or past problem areas. The primary source of information in this category consisted of academic brochures that listed STEM offerings. Other data were collected through oral means including field notes generated from a researcher’s perspective during the focus groups or interviews.

The qualitative data on the students’ STEM experience and predisposition were collected from the focus group (and individual interviews, as applicable) using a set of semi-structured and open-ended questions. The data gathering using the interview
protocol examined questions like “How predisposed is the candidate to one or more areas of STEM?” and “How likely is the student to pursue STEM after high school graduation?” Additional questions were posed to explore the students’ dispositions to mathematics and the role of music as an engagement device to enhance STEM engagement and persistence. The procedure established an audit trail to assure the trustworthiness of qualitative data collected at all research stages using the video and audio recordings, electronic transcripts, and raw field notes.

The focus group interview questions were crafted along multiple dimensions (themes) that helped answer the research questions. The individual focus group questions and in turn, the research questions, embodied a priori themes or codes that were developed ahead of examining the research data gathered—a technique useful in qualitative research in which codes (evocative content or thematic dimensions) are developed while open coding the research data. Although the study allowed for one-on-one interviews with students, no extraordinary responses were observed during the focus groups to warrant individual follow-up sessions.

Field notes were used to record impressions, pose questions, note observed biases, and document the work in progress. Homogeneous focus groups solely comprised of students or educators were conducted to capture valuable insights by recording narrative data summaries and generating transcripts based on a set of prescribed focus group questions that aligned with the research questions (see Appendices A and B). Additionally, the optional one-on-one, open-ended interviews with the selected students were structured around the research questions (see Appendix C). The data analysis steps
that helped answer the research questions and enhance an understanding of the research problem are discussed next.

**Data Analysis**

The single-case study methodology research plan was used to guide the process of collecting, recording, analyzing, and interpreting the focus group interactions and researcher observations. The analysis of recorded observations accounted for spatial, temporal, and other concrete boundaries that comprised the case study. Per Yin (2014), the recommended techniques for data analysis included the use of pattern matching, explanation building, time-series analysis, logic models, and cross-case synthesis (as applicable). Data collection and analysis typically occurred simultaneously and was iterative, involving cyclical or spiraling processes that commenced during the focus group sessions and interviews, field observations, and transcription stages to highlight recurring themes, patterns, or categories.

The analysis began by systematically organizing the data (recorded and textual transcripts) into hierarchical or relational structures, matrices, simple arrays, or other tabular formats (Microsoft Excel and Word documents). For example, a Word table was organized by rows and columns to enter the narrative data gathered from the interviews into the table cells. Yin (2014) suggested that the strength of the analytic approach for the organized data depended on applying and interpreting the claims using the evidence in conjunction with logical arguments or deductions. The criteria for interpreting the findings included identifying, in advance, any alternative concepts or strategies and rival explanations as a part of the case study’s design.
Next, Saldana (2015) pointed out the utility of using codes and coding techniques to interpret evidence gathered from the qualitative focus group and one-on-one interviews (as applicable), direct observations, and recordings. Codes facilitated the discovery, labeling or categorization, and analytic reflection of recurrent words, phrases, or themes contained in the qualitative data. Saldana recommended the “right tool for the right job” based on the nature of the specific case study (p. 3). For the case study, the following specific coding methods were examined: in vivo—direct quotation(s) by an individual or focus group participant(s); descriptive—summarizing an excerpted main topic or a discovered theme; initial—recorded first impressions (open-ended); simultaneous—two or more codes discovered within a single unit of data; and process—an “action” word or phrase that elicits a key point or idea. For case studies, Saldana recommended using a meaning-driven method such as in vivo, values, emotion, and/or dramaturgical coding. Motif coding was also appropriate in examining interpersonal participant experiences and actions.

Coding for patterns in qualitative case study research was based largely on isolating repetitive words, phrases, or themes using multiple unstructured to highly structured elicitation tasks and categorizations. Coding categories were explored across the research settings, definitions of situation, perspectives, frames of thought, processes, activities, events, strategies, relationships, and methods (Bogdan & Biklin, 1992). As data were coded, convergent or divergent trends were studied analytically until saturation was reached. Prepackaged computer programs encapsulating custom-written coded instructions and notes categorized from raw transcripts were examined to analyze textual data but not used in the study (Saldana, 2015). The Nvivo and Atlas software tools were
specifically investigated for this purpose (Atlas.ti, 2019; QSR International, 2019). However, the bulk of the data analyses was performed manually using Microsoft Excel and Word to facilitate ease of data reduction.

Broader themes were derived by defining the codes and fitting together the coded evidence in a logical, iterative manner. Multiple perspectives, methods, and information sources were triangulated and synthesized (clustered, thematized, or expressed metaphorically) to derive meaning and assure trustworthiness of data collection processes. Qualitative iterative data analysis helped in reducing many pages of text into smaller segments, then codes, and finally into five to seven key themes. Per Saldana (2015), the following methods and procedures were used to provide a practical framework to accomplish the iterative data reduction and analyses: first cycle—first pass data review focused on a single word or phrase; second cycle—edit, revise, or regroup selected passages; decoding—interpret or decipher a passage’s key meaning; encoding—applying passage labeling; and pattern recognition—identifying and isolating recurrent themes or data patterns that give insightful interpretations.

Saldana (2015) further stated that words, phrases, and data can be expressed in various ways based on differences or similarities, frequency of occurrence (repetition rate), sequence or relative placement/location in the data structure, correspondence, and causation or relationship among elements in the data structure. Additionally, iterative filtering can be performed by (a) repeating the first and second cycles; (b) identifying changes to codes, themes, or categories; (c) systematically recodifying, recategorizing, and rearranging or restructuring the data; and (d) discerning the multiple layers of findings and their interrelationships to refine qualitative data interpretations. The above
steps were taken to ultimately sift out a theoretical construct that explains the findings and supported or validated the arrived-at conclusions.

Saldana (2015) suggested that units of social organization be identified and categorized in case study research. The units include, but are not limited to episodes or events, encounters, cultural practices, organizations, participant roles, social and personal relationships, groups and cliques, settlements and habitats, and subcultures and lifestyles. The next section describes the iterative coding and sequencing procedure that was used.

**In vivo coding procedure.** In vivo coding (also called literal coding, verbatim coding, or inductive coding) was the primary technique used to develop inductive codes by directly examining and reducing the research data. The procedure prioritized and respected the focus group participants’ voices using the “verbatim principle” (Saldana, 2015, p. 105). The developed codes corresponded to words, phrases, or concepts (extracted *indigenous* terms) derived from the voices, literal responses, or vocabulary (argot) of the focus group participants.

In vivo coding captured and preserved the participants’ attitudes, perspectives, and meanings of their views, reactions, or behaviors in the codes themselves. In some cases, the codes developed provided imagery, metaphors, or other evocative content to enhance category, theme, and concept development to help answer the research questions. The coding process helped (a) deepen an understanding of an individual’s and collective group’s perspectives on STEM pedagogical engagement, and (b) grasp the meanings inherent in peoples’ experiences including what is significant to the participant to crystallize and condense meanings.
In vivo coding as a “lumper” was used in which codes were expressed in quotations and applied with less frequency such as one word or phrase for approximately every three to five sentences (Note: this is opposed to using coding as a “splitter” where each key line of data is assigned its own code—not used in the present study). Other complementary coding techniques were considered and applied to further enhance an understanding of the data collected as discussed below.

**Complementary coding procedures.** Although in vivo coding was found to be indispensable in developing codes from the transcribed data, several complementary methods were also deemed beneficial in sifting out important themes from the data. The additional methods included: (a) values coding—applicable in exploring STEM group cultural values, identity, and intra/interpersonal participant experiences, dispositions, behaviors, or actions; (b) theming the data coding—using an extended phrase from the data corpus that gives meaning to a unit of research data in developing an all-encompassing theme to explore STEM group culture beliefs or behaviors, event causality, and “belonging;” (c) causation coding—ascribing beliefs from research data regarding how and why certain (STEM) outcomes arise and applies a multiple-step coding sequence to distinguish motives and belief systems that influence human actions or phenomena—appropriate in evaluating the efficacy of STEM programs to support a grounded theory approach (for example, STEM pedagogy → student confidence → better college preparation and career success); and (d) evaluation coding—applying nonquantitative codes (example: low, moderate, high) to qualitative research data to assign attributes on the merit, worth, or significance (Saldana, 2015).
In vivo coding as a lumper was the predominant coding method used. Values, theming the data, causation, and evaluation coding were also used to help sift out the critical emergent themes. The data analysis cycles are discussed next where the role of the various coding methods was implicit in the application of the in vivo coding procedure.

**Data analysis cycles.** Three main cycles of coding and analysis were performed for each focus group session. The first cycle focused on filling in missing words or phrases while studying the actual recorded videos to ensure completeness. The second cycle led to the development of initial codes to capture the essential common and divergent perspectives, viewpoints, or emergent themes within the individual focus groups. The third cycle concentrated on refining the codes and identifying aggregate common and divergent viewpoints separately across the student focus groups and then the teacher focus groups; researcher reflections via analytic memo writing helped to condense the number of in vivo codes and provide a reanalysis of the initial coding task (although interviews and memo writing are essential in grounded theory research and not necessarily in coding tasks, the basic techniques were used in the study).

Personal researcher observation combined with reviewing the video recordings, transcripts, and researcher notes were utilized in each coding/analysis cycle. Attention was given to participant responses that called for highlighting words or phrases expressed emotionally or with vocal emphasis (features such as a loud, exuberant, or surprising reaction or the use of impact nouns, action verbs, evocative argot, clever or ironic phrases, metaphors, similes, and so on). During the coding/analysis cycles, certain in vivo codes were merited (using the ! symbol) when standout or repeating words, phrases,
concepts, or variations thereof were expressed by the participants (such as “I don’t know!” “I completely agree!” or “I highly disagree.”). The in vivo codes were then examined beyond just themes but as possible dimensions of categories or a continuum of a given property.

The transcripts were chronologically coded and analyzed for each focus group session; within each session, the codes were generated and analyzed in the exact order in which the questions were posed within each group (which was the same for each group). In organizing the array of in vivo codes, an editable document framework was prepared that allowed the separate focus group transcripts to be gathered into a single document (one each for the student and teacher categories) and aligned chronologically and in accordance with the order of the focus group questions. The framework allowed the codes to be readily developed and entered into outlined clusters that suggested categories of belonging and that facilitated a micro-to-macro mapping of the codes for each focus group and for each focus group question.

The approach further allowed the development of an aggregate picture of the collective focus groups’ responses to answer the research questions. Recall that the outline and categories of belonging were driven by a priori codes that set the tone of the in vivo codes based on the study data. The stepwise preparatory procedures used in gathering, reducing, coding, and analyzing the research data are described next.

**Procedural Steps**

The bulk of the site research activity was conducted between May and December 2019. The period coincided with the timeframe for students to decide on or commit to college enrollment, which was timely for the purposes of the research schedule. The
timeframe covered three terms which provided for diversity in the data collection: spring term (2019 graduation), summer term, and fall term. The procedural plan was prioritized and executed as follows:

1. Approval was received for the conduct of the study at two levels: dissertation committee and ESM High School (district superintendent and school principal levels), contingent on St. John Fisher Institutional Review Board (IRB) approval.

2. Permission for the study was granted by the IRB.

3. Coordinated the launch of the study with ESM High School administrators to prepare for internal outreach to prospective study participants based on purposeful sampling and selection criteria (no participant data were shared with the researcher in advance of the study).

4. Letters of introduction were electronically sent to school administrators to socialize the nature of the study and sent by invitation only to prospective study participants via email communication (see Appendix D).

5. Finalized arrangements and schedules for the study consisting of multiple focus group sessions (all sessions were to be conducted onsite at ESM High School conference/board rooms or laboratories based on availability).

6. Issued consent forms prior to the conduct of each focus group where consents covered the recording and securing of data for privacy and anonymity protection, including the sharing of any results (see Appendix E).

7. Obtained signed consent forms at the time of the study (prior to commencement of focus groups).
8. Overviewed the nature of the study and ground rules to allow for opt-out, as necessary.

9. Conducted focus groups with study participants using the student and teacher interview protocols outlined in Appendices A and B (note: one-to-one interviews were not conducted, but the interview protocol that would have been used had they been conducted is outlined in Appendix C).

10. Peer coding processes and interrater reliability crosschecks were considered but not employed due to time constraints.

11. ESM administrators were contacted to notify them of the study’s completion.


The letters of introduction and return approval letters from ESM High School were obtained and filed for the record in March 2019. Although the case study research involved minimal risk to human subjects, IRB approval was required. All the study participants were at least 18 years of age. The dissertation proposal was submitted to the IRB for an expedited review, allowing up to 1 month for approval.

Upon receipt of IRB approval, the first step was to confirm if the organization where research was to be conducted needed any further approvals of the study. A letter of introduction to the participants was prepared describing the researcher status, IRB approval of the research, and cover letters, as applicable. An explanation of rights to informed consent (form), confidentiality and anonymity, options for non-participation, ethical considerations, and minimal risk advisories was provided to each participant.

Additional approval/confirmation letters were obtained from the organizational research site along with parents’ consent, as applicable. All activities were monitored
and documented using an electronic calendar and a written journal to track milestone accomplishments. All data were safeguarded on a password-protected hard drive and stored in a combination-locked container. A chapter summary is provided next which recaps the case study research methodology and the procedural steps followed in the data gathering, reduction, and analyses.

**Summary**

The qualitative case study research methodology employed nonprobability purposeful sampling. Specific criteria and rationale were established to select the case and the participants that represented information-rich sources from within the case. Purposeful sampling, in conjunction with an operationalized NYSED Next Generation Science Standards high school curriculum, guided the process of selecting the research context for the case study. A maximum variation sampling was used to elicit multiple perspectives in matching participants to the established criteria. Purposeful, maximum variation sampling sought to encompass participants who represented a broad range of pro/con viewpoints regarding STEM pedagogy. The sampling method helped to ensure that diverse perspectives were offered over multiple dimensions of STEM learning and engagement including progressive and possibly extreme viewpoints.

ESM High School was selected for the case study research because it had implemented a progressive STEM program in accordance with the science standards and in conjunction with industry and university curricula (Project Lead the Way, 2019; Rochester Institute of Technology, 2019; Rowley, 2012). The program included an array of non-STEM electives (music, clay art, auto mechanics, cosmetology, aeronautics,
The ESM High School officials and administrators were recruited to help sample, by way of an open invitation, from the eligible population of students who participated in ESM’s Spartan Academy STEM Program including teachers who met the purposeful sampling and selection criteria. A total of six face-to-face focus groups were conducted consisting of three individual student sessions and three individual educator sessions. The ESM High School administration staff arranged for the focus groups to be privately held in a closed conference room or school laboratory setting at the conclusion of the school day. A free and open dialogue was encouraged among the participants within each of the six separate focus groups to optimize the data collection process. The focus groups were conducted in a semi-structured and open-ended conversational style. The total sample size was 33 participants with a total attrition of five.

The criteria targeted students who were at least 18 years of age at the time of the study and who participated in ESM’s STEM program during at least the period of the study or who were openly STEM-disposed. The focus was on the students’ high school STEM experience and their STEM disposition at the time of the study; STEM (pre)disposition or program experience prior to high school was not specifically used as a criterion, although it was assumed that prior exposure had played a role in molding the students’ attitudes about STEM at the time of the study. The criteria also targeted STEM teachers plus educators from elective subject domains who participated in the program including cocurricular STEM instructors.
In vivo coding as a lumper was the predominant coding method used together with other open-coding methods. Values, theming the data, causation, and evaluation coding were also used to help sift out the critical emergent themes. Three main cycles of coding and analysis were performed for each focus group session. The transcripts were chronologically coded and analyzed for each focus group session; within each session, the codes were generated and analyzed in the exact order in which the questions were posed within each group. The approach further allowed the development of an aggregate picture of the collective focus groups’ responses to answer the research questions.

In conclusion, replication logic, not sampling logic, is important in case studies. The case must be carefully selected so that it is repeatable or predicts anticipated contrasting results to either confirm or refute a theory. The qualitative research methodology was designed to answer the research questions and identify ways of closing the STEM gap. To that end, Chapter 4 will present the results of the single case study and the outcome of applying the qualitative research methodology. The contributors to the STEM gaps and the ways to close the gaps will focus on the factors that influence engagement and persistence for STEM-oriented students nearing the time of high school graduation. Of interest will be the influences that may persuade or dissuade a STEM-oriented student in his/her pursuit of a STEM major during the first year of college or upon entering the STEM workforce. The findings and conclusions of the data analysis aligned with the research questions are presented in the next chapter.
Chapter 4: Results

Introduction

A progressive STEM pedagogical strategy that leverages integrated and multidisciplinary learning environments, real-world contexts, scaffolding, collaboratives, and self-efficacy reinforcement models has been shown to enhance engagement outcomes (Akyurek & Afacan, 2013; Allen et al., 2016; Belland et al., 2015; Brown, 2012; Bruce-Davis et al., 2014; Capraro et al., 2016; Christensen et al., 2015; Connors-Kellgren et al., 2016; Duman, 2010; Fan & Yu, 2017; Gabriel, 1999; Gottfried, 2015; Hutto et al., 2015; Jackson et al., 2014; Kertil & Gurel, 2016; Kezar & Gehrke, 2017; Korpershoek et al., 2011; Mativo et al., 2013; Moakler & Kim, 2014; Mullender-Wijnsma et al., 2015; Proudfoot & Kebritchi, 2017; Sanders, 2012; Springer & Stanne, 1999; Sriraman & Lesh, 2007; Stage & Kinzie, 2009; Stieff & Uttal, 2015; Tobias, 2014; von Károlyi, 2013; Whalen & Shelley, 2010; White et al., 2012). However, barriers stand in the way of efforts to modernize the STEM curriculum and fill the gap. The legacy STEM learning siloes, and the state testing policies been at the forefront of stalling reforms. This chapter examines the issue through the lens of the qualitative data gathered from 12th-grade STEM students and educators in a focus group setting to reveal new insights.

Consider first, a fundamental gap exists in understanding the phenomenon of STEM disengagement and waning persistence particularly during the transition period between 12th grade and upon entering college or the workforce. Although students were exposed to STEM during their K-12 school years, a sudden drop in STEM major and
STEM career pursuits tends to occur upon/after high school graduation. The trend points to systemic gaps that impact graduating student-engagement outcomes in STEM. The vast body of research was found to not address the STEM gap phenomenon during this critical transition period.

The qualitative data gathering and analyses attempted to raise awareness of the factors affecting STEM outcomes during the transition period across multiple dimensions. The knowledge gained will assist in closing the gap in the body of research and enhance an understanding of the STEM gap phenomenon. Hence, the focus of the data gathering was not only on identifying the contributing factors to STEM disengagement; it was also to converge on strategies for reinforcing education and programs that foster engagement especially during the last year of high school to increase STEM persistence capacity.

Further, the data gathering and analyses examined pedagogic themes and investigated to what degree interdisciplinary synergies were operationalized via integrated, active, or immersive learning frameworks. The study endeavored to reveal how interdisciplinary relationships and synergistic embodiments between STEM and non-STEM subjects like music theory and practice contributed to reinforcing STEM pedagogy, teaching protocols, and learning environments. Shared mathematical frameworks between STEM and non-STEM disciplines that highlighted music as an engagement device were also explored. Alternative strategies or interventions were contrasted with traditional, siloed learning to qualitatively evaluate the effects on engagement outcomes. Additionally, the study explored how learning modalities stimulated brain-learning for increased engagement.
To gather the data, a focus group protocol was used followed by optional one-on-one interviews with selected study participants. Although the study allowed for one-on-one interviews with students, no extraordinary responses were observed during the focus groups to warrant individual follow-up sessions. The focus group protocol was designed to answer the research questions via a crosswalk scheme (Caplan, 2003). The data sources included high school seniors participating in ESM High School’s Spartan Academy STEM Program, the high school STEM educators, and certain non-STEM educators who delivered complementary, cocurricular instruction on behalf of the school’s STEM programs. Individual sets of focus group questions and protocols were generated, each customized for the student and the educator groups (see Appendices A and B). The data collection instruments included audio and video recordings, live observations, field notes, and transcriptions. The research questions and their partitioning for focus group data gathering purposes are reviewed next.

**Research Questions**

The research questions examined the STEM engagement issues and the overarching STEM gap problem in a manner consistent with the qualitative case study research method. Each research question (RQ#) was parsed by student and/or educator study participant as described below and in Appendices A and B, respectively. The research questions and their partitioning are repeated as follows:

1. From the student’s perspective, how does participation in a STEM learning program stimulate or deter interest in pursuing a STEM major in college or as a career choice?
2. From the perspective of the educator, how do current STEM programs contribute to or detract from STEM persistence after high school, during college, and as a career choice?

3. From the standpoint of students and educators, why might STEM persistence or sustained STEM interest upon/after high school graduation be on the decline?

4. From the perspective of students and educators, how can interest in pursuing a STEM major in college or a STEM career be increased?

The crosswalk method was used to answer the research questions using semi-structured focus group questions (Caplan, 2003). Each focus group question was crafted along certain thematic dimensions to elicit evocative content from the participants ahead of examining and coding the research data a posteriori. Tables 4.1 and 4.2 list the a priori codes that were used to extract the thematic content from the student and teacher focus groups, respectively. The tables indicate whether the themes, resonant with the a priori codes, were able to answer the research questions along the dimensions of choice (labelled as Convergence). The research data were confirmed to satisfactorily answer the research questions.

Consider for example, RQ1 in Table 4.1. The focus group questions (FQ#) were designed to highlight a dominant theme and elicit responses that collectively were used to answer RQ1 using the a priori codes listed in Table 4.1. As a further illustration, FQ1 was designed to focus on students’ “STEM affinity,” FQ2 was aimed at students’ “current experience influencing persistence,” and so forth. Taken together, the focus group questions and the inherent dominant themes via the a priori codes were able to
answer RQ1. A similar methodology was used for the teacher-based focus groups as shown in Table 4.2. The data analysis and findings based on using manual, iterative in vivo coding along with complementary open coding methods are described next.

Table 4.1

*Research Question A Priori Codes and Convergence (STEM Student Perspective)*

<table>
<thead>
<tr>
<th>RQ#</th>
<th>FQ# a Priori Codes/Themes</th>
<th>Convergence</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1. STEM Affinity</td>
<td>Yes: Answers RQ1 by examining students’ self-perspectives on their STEM affinity, past/current experience or influences, the role of creativity and group dynamics, the benefits of integrated STEM and non-STEM subjects (lessons learned), how fine arts (music) contributes to engagement, and exploiting multimodality (visual, tactile, auditory) learning environments.</td>
</tr>
<tr>
<td></td>
<td>2. Current Experience Influencing Persistence</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3. Creativity Stimulating Engagement</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4. Integrated vs. Siloed Learning Benefits</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5. Non-STEM (Fine Arts) Connections</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6. Music Stimulating Engagement/Persistence</td>
<td></td>
</tr>
<tr>
<td></td>
<td>7. Effective Learning Modalities</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>8. Sustaining Interest</td>
<td>Yes: Answers RQ3 by examining practical engagement sustainment strategies or interventions, self-perceptions (fear of math), and other factors that could negatively affect engagement and persistence for underserved or underrepresented groups.</td>
</tr>
<tr>
<td></td>
<td>9. Pedagogical Gaps &amp; Remedies</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10. Math Phobia</td>
<td></td>
</tr>
<tr>
<td></td>
<td>11. Female Engagement/Persistence</td>
<td></td>
</tr>
<tr>
<td></td>
<td>12. Disadvantaged/Underserved Engagement</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>13. STEM Influencers vs. non-STEM Careers</td>
<td>Yes: Answers RQ4 by exploring the factors influencing the choice of college major or career path including advancement, equity, and equal opportunity, and closing of gaps.</td>
</tr>
<tr>
<td></td>
<td>14. Social Justice Factors</td>
<td></td>
</tr>
<tr>
<td></td>
<td>15. STEM Thought Leadership</td>
<td></td>
</tr>
</tbody>
</table>

**Data Analysis and Findings**

This section presents a summary of the study participant demographics, the data collection process, the emergent themes from the data analysis cycles, and the study’s findings arranged by the research questions and emergent themes. A background discussion is first provided to lay the groundwork for reporting the detailed analysis and findings. The discussion addresses the anonymity of the study participants, the focus group arrangements, data handling, and the data analysis scheme employed in the study.
The qualitative data collection and analyses were *participant-agnostic*—no names were attached to any of the data or the findings to ensure anonymity. Each study participant was labeled as “Participant” and assigned a focus group number (for example, “Participant from FG#”). Except as noted, the data analysis did not differentiate the findings across gender, age, academic achievement, professional credentials, or any other socioeconomic or sociocultural variables.

Table 4.2

*Research Question A Priori Codes and Convergence (STEM Educator Perspective)*

<table>
<thead>
<tr>
<th>RQ#</th>
<th>FQ#</th>
<th>A Priori Codes/Themes</th>
<th>Convergence</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>1.</td>
<td>Past/Current STEM Pedagogy Experience</td>
<td>Yes: Answers RQ2 by drawing on teachers’ self-perspectives on past/current STEM program efficacy, perceived gaps, the role of creativity in STEM pedagogy, the benefits of integrated STEM and non-STEM subjects (lessons learned), how fine arts (music) may contribute to engagement or persistence, and exploiting multimodality (visual, tactile, auditory) learning environments.</td>
</tr>
<tr>
<td></td>
<td>2.</td>
<td>Present STEM Pedagogical Gaps</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.</td>
<td>Creative Learning Environments</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4.</td>
<td>Integrated vs. Siloed Learning Benefits</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5.</td>
<td>Non-STEM (Fine Arts) Connections</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6.</td>
<td>Music Stimulating Engagement/Persistence</td>
<td></td>
</tr>
<tr>
<td></td>
<td>7.</td>
<td>Effective Learning Modalities</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>8.</td>
<td>STEM Sustainability &amp; Persistence</td>
<td>Yes: Answers RQ3 by examining practical engagement strategies or interventions to increase persistence, addressing students’ fear of math, and factors that could negatively affect engagement and persistence for underserved/underrepresented groups.</td>
</tr>
<tr>
<td></td>
<td>9.</td>
<td>Interventions/Remedies</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10.</td>
<td>Arithmophobia</td>
<td></td>
</tr>
<tr>
<td></td>
<td>11.</td>
<td>Female Engagement/Persistence</td>
<td></td>
</tr>
<tr>
<td></td>
<td>12.</td>
<td>Disadvantaged/Underserved Engagement</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>13.</td>
<td>In-class vs. Outside Class Learning</td>
<td>Yes: Answers RQ4 by exploring varied STEM learning environments and pedagogical strategies, the benefits of small-group dynamics, social justice perspectives on career equity and equal opportunity, and closing of gaps.</td>
</tr>
<tr>
<td></td>
<td>14.</td>
<td>Small-group Collaboration Benefits</td>
<td></td>
</tr>
<tr>
<td></td>
<td>15.</td>
<td>Social Justice Factors</td>
<td></td>
</tr>
<tr>
<td></td>
<td>16.</td>
<td>STEM Thought Leadership</td>
<td></td>
</tr>
</tbody>
</table>

A total of six face-to-face focus groups were conducted consisting of three individual student sessions and three individual educator sessions. The ESM High School administration staff arranged for the focus groups to be privately held in a closed conference room or school laboratory setting at the end of the school day. A free and
open dialogue was encouraged among the participants within each of the six separate focus groups to optimize the data collection process. The focus groups were conducted in a relaxed setting using a semi-structured, conversational style. The protocols described in Appendices A and B were used to guide the conduct of the focus groups. The participants were seated in either a roundtable configuration or theater style arrangement.

Each focus group was introduced to the purpose of the study, a background on the STEM gap problem, the focus group parameters, and the ground rules for the conduct of the study as described in Appendices A and B. Letters of introduction and consent forms for recording and privacy protection were distributed and reviewed with the participants to provide a foundation for the focus group activity. Prior to conducting the focus groups, 3x5 index cards were handed out strictly as part of a warmup exercise where the participants were asked to jot down up to three items they liked or disliked about STEM.

The researcher sat or stood casually in front of the focus groups and orchestrated the data collection process. The researcher posed a question and then let the focus groups take control but reigned in the discussions when a saturation point was reached or if the discussions became tangential to the question’s focus. The goal was to observe and record strong (emotional or passionate) participant responses or interpersonal group interactions that stood out indicating the importance of the issue to the study participant(s). Such observations were noted and recorded in the summarized findings.

An outside research assistant was recruited to video and audio record the focus group sessions. Two video cameras were poised at about 45-degree angles from the front-center of the focus group settings to fully capture the participants’ reactions. An iPhone was placed at the center of the group setting to record backup audio if video
tracks were inaudible. The arrangement allowed for the researcher to intimately observe the focus group interactions and record field notes in real time.

The audiovisual recordings were saved to a computer hard drive that was password protected. The digital audio files were submitted to Rev.com to process the data and produce editable transcripts. Digital transcripts were strictly used for coding purposes and no hard copies were printed. The removable hard drive including the digitized transcripts were placed in combination-locked storage when not in use and at the conclusion of the study. The field notes and digital transcripts provided a means of triangulating the data collection such as the need for individual interviews based on noteworthy reactions or expressions of extreme attitudes or viewpoints. As previously mentioned however, no one-on-one interviews were warranted or conducted.

During the data analysis and reduction, the results for all student (or teacher) focus groups and for each relevant focus group question were aggregated to compositely answer the research questions. The data and results were organized according to the research questions using the frameworks presented in Tables 4.1 and 4.2. The results for each focus group question and in turn the corresponding research question and ultimately for the entire study were then prioritized. The prioritization was based on the dominant emergent themes, the frequency of agreement or consensus among the participants including first impressions, followed by alternative or contrarian viewpoints. The next section provides a research context and demographic summary of the participants followed by a description of the data analysis cycles performed in the study.

**Research context and participant demographic summary.** Recall that nonprobability purposeful sampling was used to guide the selection of the case study
research context and the information-rich sources from within the case. ESM High School was selected for the case study research because it was known to have implemented a progressive STEM program in accordance with the science standards and in conjunction with industry and university curricula (Project Lead the Way, 2019; Rochester Institute of Technology, 2019; Rowley, 2012). Their program included an array of non-STEM electives (music, sculpture art, auto mechanics, cosmetology, aeronautics, finance, career planning, and other subjects) in conjunction with their traditional STEM program offerings. The ESM High School officials and administrators were recruited to help sample, via open invitation, from the eligible population of students who participated in ESM’s Spartan Academy STEM Program including teachers who matched the purposeful sampling criteria.

Purposeful, maximum variation sampling was used to recruit participants representing a broad and diverse range of pro/con perspectives, including progressive and potentially extreme viewpoints on STEM pedagogy over multiple dimensions. An example of the maximum variation sampling used in the study was extending invitations to eligible participants in both mainstream STEM classes and related STEM program electives outside of the traditional STEM offerings to ensure capturing a broad spectrum of ideas, opinions, and viewpoints.

Recall that the study was keenly interested in students who were at least 18 years of age, were generally STEM-disposed, and were active in ESM’s STEM program at the time the study. Knowledge of the students’ high school STEM experience and their STEM disposition was pivotal to the study as students were on the front-line and most impacted by STEM pedagogical policies, practices, and interventions. The imperative
was to ensure a meaningful population of students who met the sampling criteria for a thorough study. However, STEM (pre)disposition or program experience prior to high school was not an explicit criterion, although it was assumed that prior STEM exposure had played a role in molding the students’ attitudes at the time of the study.

The maximum variation sampling also applied to STEM teachers and educators from elective subject domains who participated in ESM’s STEM program including cocurricular instructors. The teacher-side experiences and opinions on STEM pedagogy and engagement not only complemented the students’ perspectives but also reinforced the study’s validity. The joint data collected allowed for a broad comparison between the student and teacher focus groups along similar lines of inquiry and dialogue to sift out common or disparate themes that meaningfully helped answer the research questions.

Table 4.3 summarizes the representative categories of ESM students ($N_{Stotal} = 15$) and educators ($N_{Etotal} = 18$) who were recruited for the study across the high school’s STEM program activities. Three separate focus groups (FG#) for each category were conducted with typically between four and seven participants in each group prior to attrition. Two additional focus groups were conducted to compensate for the attrition and ensure data-rich findings. The focus group attrition and participant recruiting challenges were attributed to:

1. A limit on the number of eligible STEM students able to participate;
2. Last-minute “no shows” and unexpected schedule conflicts that forced several student and teacher participants to exit the focus group sessions prematurely leading to a suboptimal focus group size (Table 4.3 lists the attrition that typically occurred two-thirds of the way or more through certain sessions);
3. Dates selected by the school officials to conduct the focus groups that were further constrained by academic schedules or other commitments (Note: the focus groups could only be conducted in June, October, and December 2019 due to schedule constraints);
4. Virtually no access to students for individual follow-up interviews; and
5. The school officials enlisting non-STEM teachers at the last minute to increase the focus group size due to the unavailability of STEM teachers, although the non-STEM teachers who participated were actively involved in elective classes that complemented ESM High School’s Spartan Academy STEM Program.

Table 4.3
Profile of Focus Groups

<table>
<thead>
<tr>
<th>FG#</th>
<th>Category</th>
<th>#Participants</th>
<th>#Attrition</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Students</td>
<td>5</td>
<td>1</td>
<td>All STEM-inclined, 20% Female</td>
</tr>
<tr>
<td>2</td>
<td>Students</td>
<td>4</td>
<td>0</td>
<td>All STEM-inclined, 50% Female</td>
</tr>
<tr>
<td>3</td>
<td>Teachers*</td>
<td>4</td>
<td>2</td>
<td>STEM instructors, 50% Female</td>
</tr>
<tr>
<td>4</td>
<td>Teachers*</td>
<td>7</td>
<td>0</td>
<td>STEM/non-STEM, 43% Female</td>
</tr>
<tr>
<td>5</td>
<td>Students</td>
<td>6</td>
<td>2</td>
<td>All STEM-inclined, 33% Female</td>
</tr>
<tr>
<td>6</td>
<td>Teachers*</td>
<td>7</td>
<td>0</td>
<td>STEM/non-STEM, 57% Female</td>
</tr>
</tbody>
</table>

*Note. Teacher focus groups primarily consisted of traditional STEM, non-traditional STEM (auto mechanics, engineering design, aeronautical engineering, construction, coding, robotics), and non-STEM (cosmetology and hairdressing, music, art design, graphic arts) educators where the latter represented elective subjects that tied into ESM High School’s Spartan Academy STEM Program. FG#4 had no music-elective teachers. FG#6 included three math teachers.
Although the study was unable to achieve the desired target population maxima 
\(N_{\text{Smax}} = 20, N_{\text{Emax}} = 10\) within no more than two focus groups per category, the findings 
elicited multiple perspectives and yielded rich, diverse insights on the STEM gap issues. 
The study was the first of its kind to examine the factors that could influence one to pivot 
away from STEM by the time of high school graduation and along multiple dimensions. 
Oftentimes, the influential factors were rooted in issues of self-efficacy, as will be later 
discussed. The results and findings were derived after an exhaustive series of data 
reductions and analyses of the session transcripts using iterative in vivo coding cycles 
and multiple sequencing to sift out the dominant, emergent themes.

Although in vivo coding was the predominant coding method used in the study, 
values, theming the data, causation, and evaluation coding were also used to sift out 
important emergent themes from the research data. The role of the various coding 
methods was implicit in the application of the in vivo coding. The results of the data 
coding/analysis procedure are given next showing how the findings answered each of the 
research questions followed by a detailed qualitative analysis discussion.

Findings

The focus group questions (FQ#) together with the codes derived from the third 
cycle of analysis were used to generate the findings that answered the research questions 
(RQ#). The aggregated findings across all the student focus groups were used to answer 
research questions RQ1, RQ3, and RQ4. The findings for the student focus groups are 
provided in Appendix F (see Table F1). Similarly, the aggregated findings across all the 
educator focus groups were used to answer research questions RQ2, RQ3, and RQ4. The 
findings for the educator focus groups are provided in Appendix G (see Table G1). The
aggregated findings described the themes that emerged, their meaning, and how the
tabes answered the research questions.

The first several steps in the approach involved developing micro views across
each focus group and then forming a macro view perspective across each focus group
category (students or educators) considering the a priori codes. This corresponds to Steps
1-4 in the micro-to-macro flow map of Figure 4.1. The goal then was to ascertain the
collective views of the focus groups for each category and focus group question and to
identify areas of agreement (convergence) or disagreement (divergence) including
alternative viewpoints using Steps 4-6 in Figure 4.1. Next, Step 7 was used to synthesize
the findings across all the focus groups (students and educators). The final coded results
provided a fully synthesized macro view of the focus group responses to arrive at the
findings and conclusions for each research question (Steps 7 and 8). Finally, the
synthesized findings were recast into a dominant-themes framework to develop the
implications and recommendations (Steps 8 and 9) as discussed in Chapter 5.

The data analysis corroborated many of the literature review findings on the
STEM gap contributors identified in Chapter 2. However, several new and unanticipated
findings also surfaced and will be discussed later. The key findings and conclusions are
given next followed by a detailed review of the results organized by the research
questions.

**Discussion.** An analysis of the qualitative data using the methodology of Figure
4.1 surfaced several dominant themes that answered the four research questions (RQ1-
RQ4). The results of the data analysis for the student- and educator-based focus groups
are shown in Appendix F, Table F1 and Appendix G, Table G1, respectively. The results
and findings are organized by the research questions and provide further glimpses into the relevant issues, concerns, and opinions on STEM engagement and STEM gap causality.

**RQ1** attempted to qualitatively gauge the effectiveness of current STEM programs and their influence on post-secondary STEM pursuits from a student perspective. The data analysis revealed five core themes that emerged from the study: sustainable engagement directly proportional to STEM affinity, detrimental legacy silos, progressive STE(A)M fabric, subpar marketing and outreach, and systemic multiorganization dysfunctionality. Appendix F, Table F1 and Appendix G, Table G1 list other relevant themes and findings which will be further discussed in the next section.

Next, **RQ2** examined the effectiveness of current STEM programs and their influence on students’ post-secondary STEM plans and pursuits from an educator perspective. The data analysis surfaced the following five core themes: nurturing STEM affinity, state testing failures, monolithic learning, overhyped messaging, and
perpetuating stereotypes. Although these themes were the most dominant, additional themes emerged and will be further highlighted in a later section.

RQ3 explored the factors that tended to erode STEM interest upon/after high school and that contributed to widening the STEM gap over time from both a student and an educator perspective. Again, five core themes emerged as follows: no child left behind, integrated and multidisciplinary practical learning, filling artificial quotas, uninformed career counseling, and socioeconomic and sociocultural biases. Other themes also emerged that either reinforced or augmented the five core themes and findings. The additional findings will be further discussed in a later section.

Finally, RQ4 probed into strategies or interventions that could be used to increase STEM engagement and persistence to narrow the STEM gap from both a student and an educator perspective. The analysis yielded five additional findings as follows: maintaining the status quo, progressive strategies missing, mixed messaging, support systems and failover, and democratizing STEM. The additional findings for RQ4 will also be explored in greater depth in a later section.

A dominant-themes lens will be used later to establish a platform to articulate the implications of the findings, develop recommendations and action plans, and suggest possible interventions to enhance STEM engagement and fill the gap. The detailed findings, individually across the student and teacher focus groups and aligned with the research questions, are presented next. Each of the a priori dimensions corresponding to the focus group questions is also introduced and organized by the research questions. A detailed discussion begins with the student focus group findings that were used to answer the first research question, RQ1.
Efficacy of current STEM programs and their influence on post-secondary STEM pursuits: students’ perspectives. RQ1 which asked, *From the student’s perspective, how does participation in a STEM learning program stimulate or deter interest in pursuing a STEM major in college or as a career choice?* probed into the students’ high school experience and how that experience affected their decision to pursue a STEM field upon graduation. The results of the data analysis for the student-based focus groups are provided in Appendix F, Table F1. The findings for RQ1 lent to a micro view of the student perspectives as a first step in developing a macro view understanding of the STEM gap problem. The detailed findings of the student focus groups in answering RQ1 provided an important foundation for the study as follows.

**Student focus group findings.** The sections that follow will individually address the findings for the following seven a priori dimensions: (a) STEM affinity, (b) current experience influencing persistence, (c) creativity stimulating engagement, (d) integrated versus siloed learning benefits, (e) non-STEM (fine arts) connections, (f) music stimulating engagement/persistence, and (g) effective learning modalities. These dimensions correspond to the first seven focus group questions (FQ1-FQ7) used to answer RQ1. The next section addresses the first dimension, STEM affinity.

*STEM affinity.* As the student focus groups (FG#1, FG#2, and FG#5) were the primary focus of the data collection to build a foundation for the present study, the main interest was to tap into their experiences, perspectives, and opinions. The aggregated codes and themes that emerged from the student focus group sessions were prepared and are explained as follows. The teacher focus group findings, which were conducted to
provide complementary perspectives on STEM engagement and persistence, are covered separately and presented later in this chapter.

The student focus group sessions were designed to solicit feedback from ESM High School seniors who were actively participating in ESM’s Spartan Academy STEM Program, including related elective classes and/or cocurricular STEM activities. The first question attempted to qualitatively gauge the students’ STEM affinity in their own viewpoint by asking, “Why (or why not) are you STEM-inclined and how do you rate your STEM affinity (high/low)?” The rationale for asking this question was to gain a better understanding of whether one’s innate interest in STEM versus a casual interest could make a difference in sustained STEM engagement upon high school graduation.

In response to the question, all the students across FG#1, FG#2, and FG#5 considered themselves as having moderately strong to high STEM affinity, although they admitted having interests in other non-STEM areas and subjects. A few of the participants were undecided as to a college major and career path at the time of the study but thought they would most likely pursue some aspect of STEM. A clear majority of the students planned to enter a STEM field that included the healthcare and medical professions. Several of the FG#2 participants pointed out that in addition to their self-interests in STEM, their parents and families significantly influenced their choice to pursue STEM. They also mentioned that *affinity nurturing* can work both ways, either for or against developing STEM interest, depending on how the dynamics play out between innate interest and outside influences where some influences or environments can discourage interest.
Whereas participants in FG#1 and FG#5 emphasized the importance of practical, real-world exposure and hands-on experience (for example, “building things”) in developing STEM interest, a participant in FG#2 thought that competitions played a valuable role (for example, robotics tournaments). The FG#1 participants stated that subject diversity in STEM, which matched students’ interests, made a significant positive difference and stressed the importance of non-siloed, connected, and eclectic subject matter. The FG#1 participants also believed that all the STEM letters were important in the aggregate and were interchangeable depending on the projects, contexts or applications, and goals.

The FG#1 participants particularly agreed on the efficacy of nontraditional (non-siloed) learning strategies and further emphasized the need for a nurturing learning environment that embraces diverse curricula (pointing to STEM and the arts or STEAM), group project interaction (project-based learning or PBL), teamwork, and fostering a competitive spirit. One of the participants in FG#1 stated that a competitive spirit required one to be technology motivated to begin with, which reinforced the statement from one participant in FG#2 about the importance of competitions. The FG#1 participants also discussed embracing challenge and failure in building confidence and that these contributed to career preparedness. The participants in FG#5 similarly stated that experiential influences and exposure to real-world problems and challenges was character-building. The FG#1 participants further discussed the importance of maintaining continuity in STEM learning and prior experience (“exposure”) which can influence STEM persistence. The same point was reinforced by participants in FG#5. Several of the participants in FG#5 also mentioned the need to nurture inclusivity to
mitigate gender bias in STEM and to make the STEM learning experience more enjoyable by reducing or eliminating the state testing and scripted programs.

Overall, the student participants reasonably explained why they were STEM-disposed. According to them, the ESM High School staff had provided leadership and guidance on navigating the vast array of STEM and non-STEM higher education and career opportunities, but improvement was cited. No specific policies or procedures were identified that fully explained how career guidance had been delivered in view of multiple decision variables. Such guidance was found to routinely come from the teachers rather than from the school counselors—a significant and valuable finding that was later corroborated by the teachers and that highlighted an important STEM gap. The issue will be further discussed under the teacher focus group data analysis sections. It was also verified during the focus group sessions that a meaningful baseline had been established to proceed with the rest of the focus group activities. The next section explores more deeply the students’ STEM experiences at ESM High School and how their experiences have influenced their decisions to pursue STEM after high school graduation.

Current experience influencing persistence. The focus group question asked, “How would you describe your current STEM experience and its influence on your choice of a college major and/or career (How does it influence your pursuit of STEM fields after high school)?” It is safe to infer that a person’s decision to pursue a STEM field after high school either academically or professionally is dependent at least in part on their secondary school STEM experience. If the conditions were conducive to advancing a student’s interest in STEM following high school, then one could reasonably
conclude that the high school learning environment likely had an overall positive effect on the student’s decision; on the other hand, the inverse is not necessarily valid.

It is unclear whether a correlation or association exists between a student’s level of disinterest in STEM having experienced adverse conditions during high school. What can be stated with certainty is that a student’s lack of interest in STEM after high school would likely be due to a variety of factors, including their own relative interests in STEM or other fields to begin with. For instance, a bad STEM experience in high school might drive a student to aggressively pursue a STEM field for the purposes of proving to themselves they can succeed or to strive for STEM policy reforms. The above question attempted to isolate the factors that contributed to or detracted from the students’ interest in STEM in high school and how that experience influenced their decision to pursue a STEM major or a STEM field upon graduation.

The FG#1, FG#2, and FG#5 student participants expressed an overall positive STEM experience at ESM High School. ESM High School’s attempts at bridging the middle high school and high school STEM programs using a less-siloed approach during middle school provided for continuity and helped stimulate engagement. The students were made more aware of college/professional and trade/vocational career pathways. The FG#1 participants particularly thought the STEM program continuity coupled with student persistence (not giving up) and building on early exposure with ongoing diverse offerings that matched student interests were synergistically influential in their STEM career/job pursuits. Participants in FG#1 also called for a balanced “push” toward college/professional and vocational/trade career pathways. Indeed, vocational interests
were also deemed STEM-based, and offering individuals the choice of a trade job or professional career path (not pushing a unilateral agenda) was considered very important.

The FG#2 participants on the other hand, focused more on positive teacher motivation and experiences (attitude, practices) and creating nurturing learning environments for enhancing STEM engagement. They emphasized the benefits of teachers exposing the students to real-world team settings, including arranging tours at engineering and technology companies, multidisciplinary synergies, and integrated product team environments. Several of the FG#1 participants also underscored the importance of curating environments that nurture STEM interest through real-world learning opportunities where students can gain hands-on, practical experience in the classroom, noting that internships were highly useful in “testing” one’s interest in a STEM field before entering it. One of the FG#1 participants offered the following perspective on internships: “One’s willingness to rebuild an auto transmission is like testing to see if they want to be an auto mechanic.”

The FG#1 participants stated that peers can influence one’s choice in pursuing a college/professional or a vocational career pathway. They recognized the demand for trades and skills-based training as a STEM career path and have seen many of their peers and past graduates become successful in a range of traditional and nontraditional STEM fields. Their teachers have also exposed them to the various opportunities and options in STEM. The FG#5 participants further emphasized the positive impact of ESM’s diverse STEM offerings, electives, and clubs and that the traditional and nontraditional STEM courses, programs, and clubs have sparked interest and created opportunities for growth.
Overall, the student participants across the three focus groups thought that ESM’s Spartan Academy STEM Program had positively affected their choices to pursue STEM after high school. They also did not want to subscribe to the widely held belief that STEM was strictly a college/professional-level pursuit. The next section expands on the theme of STEM engagement during and after high school focusing on how creative learning environments in high school may help to further spark expanded interest in pursuing STEM fields.

*Creativity stimulating engagement.* The focus group question asked, “How could creative learning environments further stimulate an increase in STEM engagement?” The collective STEM domain cultivates a necessary set of knowledge and skills for people and nations to compete globally on two fundamental fronts: (a) technologically for innovation and military might, and (b) economically for commercial market dominance. That is why the subject of STEM engagement and persistence becomes so critical. It starts by attracting people into the STEM pipeline which is equally critical. However, the typical view of STEM is that it represents a collection of fact- and logic-based disciplines that can be quite challenging and require a great deal of personal investment to become STEM-proficient. Traditionally and especially in siloed learning environments, STEM has been taught as individual sets of subjects and in the absence of creative (non-STEM) content or styles; indeed, the range of high school classes taught that intentionally combined STEM and non-STEM subjects was very limited at best and often well outside the *mainstream* curriculum. The field of architecture offers an exception as it embodies both engineering and art/design disciplines.
Creating a dynamic learning environment that brings into play multiple, novel learning devices and strategies such as introducing exciting real-world contexts and applications into the learning process, was expected to elicit curiosity and increased interest in a universe of STEM possibilities. The example of *the science of sound and the art of music* has often been used to illustrate the idea, but what if music (or any representative art form) could be used in a new way to engage students’ interest in STEM to increase engagement? The question opened a line of inquiry and reasoning on the role of creativity in STEM, for creativity leads to innovation and ultimately to opportunity.

According to participants across the three focus groups, creative processes and environments in STEM pedagogy were considered paramount. A synthesized view across the focus groups on this theme identified three basic contexts, in terms of (a) the freedom to engage in out-of-the-box brainstorming and experimentation (creative problem solving), (b) exploiting STEM and non-STEM synergies for innovation and purposeful (humanitarian) applications, and (c) the advantage (satisfaction) of applying a personalized approach and creatively developing customized solutions to address real-world needs. Participants in FG#5 and FG#1 emphasized that creativity further enabled future thinking and enjoyment that enhanced the STEM experience. Further, the creative process itself can inherently exploit the synergies among a diversity of subjects and concepts that could help inform students about college and career choices; for example, studying the *fusion* of computer science and the graphic arts may be a catalyst for deciding in favor of pursuing a computer science major or some combination of STEM and arts fields that may be in high demand.
None of the participants disputed the perceived benefits of introducing creativity, creative processes, or creative environments that largely drew on non-STEM domains into the mainstream STEM learning environment. The themes of novelty, fun, and personal satisfaction emerged during the focus group discussions on enhancing creativity in STEM learning. No mention was made of the possible effects of diluting STEM via creative approaches or strategies. Also, there were no discussions on the “reverse effect” in which creative processes and environments could erode STEM interest and draw one closer towards non-STEM academic or career pursuits. Overall, the concept of introducing creativity into STEM learning was well received as a novel approach to increase STEM engagement. The students felt that ESM’s STEM offerings and diversity in electives kept them engaged and helped in their college/career decisions.

Whereas the question here focused on the effect of creative learning environments on STEM engagement regardless of form or type, one of the areas frequently mentioned or alluded to was the synergy between STEM and non-STEM subjects. The next section will further examine the potential benefits of integrated STEM learning. Such learning fundamentally considers the connections between the individual STEM subjects and secondarily examines the synergies between STEM and non-STEM disciplines. The integrated STEM learning considerations are further discussed below.

*Integrated vs. siloed learning benefits.* The previous question on the potential benefits of creative learning environments in STEM opened the door to exploring the additional benefits offered by an integrated STEM learning protocol. The focus group question asked, “How or why could integrated STEM learning be beneficial?” The immediate focus here is on the synergies between the individual STEM subjects and not
necessarily on the connections with subjects outside of STEM. The question takes a stepwise approach to understanding the perceived benefits of STEM learning as a “collective” approach focused across the STEM subjects, rather than on studying the subjects individually or in an isolated way. For instance, principles in science can be found in engineering and mathematics. Mathematics permeates science, engineering, technology, and so forth. Can these subjects be taught together in a new way to enhance their impact on the learning process and on STEM engagement? The focus group question here asks a similar question to the previous one above and will be revisited later in a slightly different context. The purpose for asking the question in several ways was to gain deeper insight into the issue using a multiple-inquiry approach.

To begin, the participants across the three student focus groups unanimously agreed on the importance of integrating the STEM subjects. Examples were given of past multidisciplinary group projects where this approach had been used (for example, the Mars Project and the Lake Cleanup Project). Several of the participants in FG#1 immediately cited STEM with the arts (STEAM) and STEM with arts and research (STREAM) approaches that they thought were effective and less rigid or formulaic (Note: the focus groups were moderated by the researcher to avoid going too deep into the non-STEM synergies at this stage of the data collection since that would be covered in a later question). Each of the focus groups saw the benefits of integrated, multidisciplinary, and practical STEM problem solving in a group setting. The approach was considered a catalyst in gaining a “big picture” understanding of the way things work in the real world. Participants in FG#2 offered the example of a police forensics STEM problem to illustrate the synergies between science, biology, chemistry, and mathematics.
pointing out that it was not just about one or two subjects and seeing how they all came together was a very enlightening experience.

The participants in FG#2 felt that ESM High School had done a reasonably good job at integrating the STEM subjects including certain non-STEM subject matter, but that the school’s efforts on this front should be expanded. They stated that the success of any integrated program or curriculum was teacher dependent, where some teachers were in a better position than others to relate the different content or subject matter. The teachers who taught multiple (STEM) subjects had a greater capacity for appreciating the underlying connections, according to the FG#2 participants.

None of the participants across the three focus groups disputed the perceived benefits of an integrated STEM learning environment, and the idea was unanimously well received as an approach to increasing STEM engagement. The student participants felt that ESM High School’s support of integrated STEM learning opportunities kept them engaged and helped in their college/career decisions, and that they would have liked to see this type of learning expand sooner.

The question here focused mainly on a STEM learning approach that integrated or related the individual STEM subjects. The following section will explore the integration or interconnection of STEM and non-STEM subjects and the potential benefits on STEM learning. Such learning fundamentally considers the connections between the individual STEM subjects and the fine arts such as music. The relevant considerations are further discussed next.

*Non-STEM (fine arts) connections.* The viewpoint on the inclusion of non-STEM subjects including the fine arts into the STEM curriculum was two-fold. The compound
focus group question asked, “Do you believe that STEM and the fine arts (such as music) are interconnected, or should the subjects be taught entirely in isolation? Explain.” One viewpoint was that the fine arts for example, expanded opportunities in STEM for experiential learning that transcended any one discipline and linked to practical, real-world problem-solving applications. Another viewpoint considered the dilution of STEM through the introduction of non-STEM subjects that some considered distracting, irrelevant, or of little to no value to STEM learning let alone engagement. The previous question focused on a STEM learning approach that integrated or related the individual STEM subjects. The question here extended that line of inquiry and reasoning by exploring the integration or interconnection of STEM and non-STEM subjects in STEM learning. Once again, such learning fundamentally considers the connections between the individual STEM subjects and the fine arts such as music.

Generally, the participants across the three focus groups believed that STEM plus the fine arts or STEAM, was an enabler for STEM engagement/persistence. They had indicated a strong belief in the interconnections between STEM and the fine arts. In fact, several of the participants in each of the focus groups found the rigid STEM-only education and workforce agenda to be outdated and potentially misleading. Participants in FG#5 acknowledged that the natural relationships and connections between STEM and the fine arts facilitated the emergence of self-expression, creativity, and innovation. However, a best-case strategy for achieving a connective fabric was deemed challenging due to the state standards governing the curriculum hence, an uncertain strategy abounds and remains elusive according to a couple of the FG#5 participants.
Several of the participants in FG#2 and FG#5, although in agreement with the likely positive impact of the fine arts on STEM engagement, offered a reciprocal view. A possible outcome could be where STEM opens a door to gaining a deeper understanding of the fine arts (such as music), thus potentially drawing one away from pure STEM fields of study. Whereas most of the participants across the three focus groups saw merit in using the fine arts as an enabler for enhancing STEM interest, the minority viewpoint was that the strategy remains uncertain; furthermore, including the fine arts in STEM was not anticipated to add high value to any engagement/persistence initiative. Nonetheless, most of the participants understood the connection between creativity and the fine arts and their potential positive impacts on STEM learning.

The student participants in the three focus groups felt that ESM High School was already on a successful path of integrating the subjects. They cited the example of a class on the physics of sound wave propagation, acoustics, and the aesthetic design of music rooms that bridged the art of music and the science of sound. However, the school’s efforts at bridging disciplines and programs required further development according to many of the participants. None of the participants saw the inclusion of the fine arts into the STEM curriculum as detrimental. Indeed, the inclusion of the fine arts into the STEM curriculum was deemed beneficial to STEM learning and engagement, but a certain degree of skepticism was expressed regarding the implementation of an effective near-term strategy and the long-term implications of this approach.

The following section will extend the discussion on the qualitative impacts of music on the level of STEM interest and engagement. Music has been used in various STEM pedagogical interventions as a learning enabler to relating musical styles and
rhythms to topics in science, physics, and mathematics providing for practical learning contexts. The use of music as a STEM learning-engagement device is addressed next.

*Music stimulating engagement/persistence.* Music has a direct relationship to mathematics, science, physics, and technology. Indeed, math cuts across virtually every discipline in one way or another. It has been conjectured that math could act as a bridge between the STEM and music domains and that such a relationship could be exploited to expand interest and engagement in STEM fields. Fundamentally, it is an attempt to cast STEM in a practical and enjoyable light and to explore deep-rooted disciplinary connections that could lead to innovations both in STEM and non-STEM fields.

For example, a strong connection exists between math, technology, engineering, and music when it comes to instrument design or in the acoustical design and construction of a sound chamber. The above examples and relationships were discussed in Chapter 2 and are now revisited. Here the question is asked, “How might non-STEM subjects like music enhance STEM engagement/persistence?” The question examined at a more granular level the specific connections between STEM engagement and persistence and music as a follow-up to FQ5. Music was offered as an elective as part of the ESM High School STEM program. A potential strategy explored the math-music connection and its effect on multidisciplinary STEM engagement/persistence.

Participants in FG#1 and FG#5 felt that music, as an enabler for increasing STEM interest, depended on one’s interest or passion in the domain of music beyond merely listening to music for personal enjoyment. A passion for music would have to encompass a deeper interest in theory, composition, music production, sound fidelity, innovative instrument design, and so forth. Several of the participants in FG#2 focused more on the
connections that would likely attract musicians to STEM, namely music production which can inspire STEM interest especially when combining music with technology, math, software, and art.

Across the three focus groups, a synthesis of the main themes that emerged related to this question were as follows: (a) science was at the core of the question; (b) fine arts like music were considered emotion-based, self-expressive, and subjective-interpretive (“shades of grey” or a continuum) whereas STEM was viewed as technical and logic-based (black and white); and (c) people can be predisposed one way or the other, but an affinity for music does not mean a penchant for STEM (a discussion ensued on the synergies between the right-hand-side and left-hand-side lobes of the brain), although some may have a dual predisposition. Other considerations raised by FG#5 participants were (a) a person’s willingness to face the rigors and challenges of STEM learning in the absence of the fine arts like music; (b) how music could help one face the rigors of STEM by providing an “offramp” to understand and appreciate the inherent scientific context and mathematical structures; (c) persistence in expanding frames of thought to overcome the perceived disconnections between STEM and the fine arts such as music; and (d) achieving a level of self-preparedness in embracing failure as a learning experience in the context of grasping STEM and non-STEM learning synergies.

However, the findings here were inconclusive. According to participants in FG#1 and FG#5, there was no clear or obvious “entry point” for music as a STEM engagement enabler and no apparent evidence to suggest that music had any measurable impact on STEM engagement. Paraphrasing one FG#5 participant, *it was possible that one could open a door to the other* (for example, music to STEM), *but it is not always evident.*
Furthermore, there was no apparent indication of music’s impact as an elective on STEM engagement. None of the participants at the time of the study made any reference to being actively engaged in a music elective although several participants said that they had studied some music and/or had learned to play a musical instrument. Although it was unclear at this point whether music had any sort of measurable or known impact on STEM learning and engagement, the participants offered useful qualitative insights into the possible connections and strategies that could be considered.

At this point, the nature of the focus group questions shifted from issues of STEM learning environments and content and curriculum to examining more closely the impact of learning modalities on STEM engagement. The question leveraged concepts from the prior question on music to see what learning modality worked best for students (visual, tactile, audible, or hybrids thereof). The preferred learning modalities for STEM student engagement are discussed next.

**Effective learning modalities.** The method, style, and rate of assimilating knowledge and information vary from student to student as discussed in Chapter 2. Some students are fundamentally visual learners whereas others prefer tactile learning or a combination of modalities. There is no single technique that will always work best in all cases, and often it comes down to a combination of techniques that will work best for an individual with one dominant modality usually surfacing for a given learning situation. The compound question asked here is, “How do you learn (tactilely, visually) and why do certain learning methods work best for you?” The question was designed to explore the modalities that were most dominant and why one was preferred over another in the context of STEM learning environments. Of special interest was how auditory or audible
learning ranked as a modality to tie findings to the previous question on music as a STEM engagement enabler.

Overwhelmingly, visual and tactile learning were cited as the most effective modalities across all the student focus groups. The FG#2 participants admitted less dependence on audible or auditory learning whereas the FG#1 and FG#5 participants never addressed the viability of auditory learning. The FG#2 participants stated that some (limited) book learning was good, but most of the participants agreed that practical, real-world, interactive problem solving as a learning experience was highly preferred. They referred to it as watching then practicing inferring the combination of visual and tactile learning modes as being most effective.

The participants were in general agreement that visual and tactile experiences were naturally preferred modes of learning and that auditory learning was less important; again, the feedback corroborated that music and sound were not major contributors to STEM engagement vis-a-vis small-group PBL protocols. However, the nature of a project may depend more on sound as an observable or a measurable feature, but there was no clear relationship to music as a STEM enabler in this context. On the other hand, everyone concurred that an auditory modality had its place in STEM learning simply by virtue of the need for verbal communications and listening. A participant in FG#2 anecdotally offered that music was a means of relaxing and expanding learning capacity.

The next section examines the findings from the data analysis that were used to answer the second research question, RQ2. The question was concerned with the effectiveness of current STEM programs and their influence on students’ post-secondary
STEM plans and pursuits from an educator perspective. The perspectives and data findings are provided as follows.

**Efficacy of current STEM programs and their influence on post-secondary STEM pursuits: educators’ perspectives.** RQ2 which asked, *From the perspective of the educator, how do current STEM programs contribute to or detract from STEM persistence after high school, during college, and as a career choice?* explored the students’ high school experience and how that experience affected their decision to pursue a STEM field after graduation from the educators’ perspectives. The findings for RQ2 lent to a micro view of the educator perspectives as a next step in developing a macro view understanding of the STEM gap problem. The results of the data analysis for the educator-based focus groups are provided in Appendix G, Table G1 and are discussed in the next section.

**Educator focus group findings.** The educator focus groups provided valuable insights into STEM pedagogy and engagement that highly complemented the students’ feedback. The educators’ perspectives facilitated a broad comparison of opinions along similar lines of inquiry and dialogue with those of the students to exculpate the emergent themes and answer research question RQ2. The sections that follow will individually address the findings for the following seven a priori dimensions: (a) past/current STEM pedagogy experience, (b) present STEM pedagogical gaps, (c) creative learning environments, (d) integrated versus siloed learning benefits, (e) non-STEM (fine arts) connections, (f) music stimulating engagement/persistence, and (g) effective learning modalities. The next section will address the first dimension, a longitudinal view on STEM pedagogy drawing on personal experience.
Past/current STEM pedagogy experience. Recall from the analysis of the student focus groups that sustaining or increasing STEM engagement and persistence depends on two important factors: (a) a student’s STEM affinity, and (b) the academic (or organizational) system’s willingness to build and nurture STEM capacity beyond what standard protocols advise. The factors in unison emerged as an important finding that was unapparent in the extant body of research. A previous section addressed the student-side perspectives. The underlying question here is, “How do STEM programs today differ from those in the past?” The educator-side perspectives on the question are addressed as follows.

To begin, the national campaign to expand the STEM agenda has been active in one form or another for over the past 20 years. The nature of STEM programs in academia and industry over the years has evolved at a slow pace stirring debate over change efficacy. The matter of change efficacy considers the significance of the changes made, what exactly has changed, the barriers to change, and how the changes have impacted STEM pedagogy and students’ STEM engagement level. The STEM campaign is more active today than ever. The central question asked here is, “How do STEM programs differ today based on your own past experiences?” The question probed the experiences and opinions of the participants in their role as teachers by asking them to reflect on the ways that STEM had been taught in the past compared to how it is taught today. The teacher focus groups provided complementary perspectives to those of the students on STEM engagement and persistence—clearly, the people on the front lines most affected by STEM policies and practices.
Unsurprisingly, in response to the focus group question, most of the participants in FG#3, FG#4, and FG#6 characterized STEM pedagogy over 10 years ago as highly structured, siloed, rigorous, and lecture (sit and get) based. They felt that present STEM programs were more “liberal” but continued to embody a legacy of siloed form, fit, and function with constraints added. The state education board (NYSED) had imposed standards on curricular content and delivery and stressed teacher accountability and a “no child left behind” mentality. The remnants of a siloed learning approach combined with the existing curricular constraints have instigated a change mindset. The fallout has urged ESM High School teachers to issue internal guidance on best practices meant to expand the STEM learning experience for their students.

According to participants in FG#4, the ESM High School educators had made strides in overcoming the inertia underpinned by the belief that “if it isn’t broken, don’t fix it” but the counter belief by some has been, it is broken and needs fixing. Although, their efforts had only scratched the surface. Participants in FG#4 stated that the inertia has been due in part to subject-class territorial attitudes coupled with a fear of change that intentional or not, perpetuated the status quo. To that end, the teachers have worked on eliminating a “one size fits all” or monolithic STEM learning model by developing interdepartmental relationships and joint strategies to deliver innovative, practical content in conformance with the NYSED’s Next Generation Science Standards (NGSS), stated participants in FG#4.

The growing emphasis today has been on STEM learning that leverages practical, hands-on, and inquiry-based problem-solving activities. ESM High School continued to use project-based learning (PBL) protocols and was pivoting towards creating a STEAM
fabric via an integrative, multidisciplinary pedagogical approach. However, the current strategies to infuse the arts and humanities into STEM have been only marginally successful and remained challenging.

Participants in FG#3 and FG#4 found it challenging to transform a monolithic STEM pedagogical model that applied repeatable content and processes in accordance with NYSED guidelines, into a progressive model that could be adapted to meet the needs of each class of students going through the program. An added challenge was the need to consistently deliver a customized program that would stimulate interest, spark knowledge discovery and understanding, and incentivize students to make informed decisions knowing that each class of individuals has different needs and expectations.

Equalizing or democratizing the field of STEM opportunities was one step in that direction, said participants in FG#4. Additionally, it was recommended that the school administration adapt the STEM program to address the students’ needs, provide sound career guidance, enable them to make informed career choices, and encourage their individual passions instead of using a monolithic approach. The strategy could conceivably increase the number of internships, corporate scholarships, and college credits given to STEM (and non-STEM) high school students resonant with their fields of interest, thus creating a wider range of opportunities.

Compared with other Central New York high schools, the ESM High School STEM educators were very proactive in seeking ways to synergize aspects of STEM not only between the STEM subjects themselves but also with other subject areas, according to participants in FG#3 and FG#4. Efforts at finding synergies had become somewhat of a norm at ESM High School. They cited some success at incorporating science and
technology in certain non-STEM classes over the past 10 years (for example, introducing concepts from Chemistry into Cosmetology or the Culinary Arts) but integrating mathematics had been more difficult. Notwithstanding, the growth in interactive and engaging math activities that were centered on practical or real-world problem solving, in lieu of the lecture-oriented style of the past, had been well received by teachers and students alike, according to participants in FG#6. Participants in FG#4 on the other hand, stated that the limits on teachers’ time and school resources have stymied efforts to exploit multidisciplinary synergies more fully. Nonetheless, efforts continued at disrupting siloed teaching patterns using a cooperative, team-based coordination plan developed by the educators.

Further, participants in FG#3 and FG#4 agreed that the school’s PBL protocols had helped students adapt the necessary soft skills (that is, literacies in reading, writing, public speaking, and the humanities) and integrate them in STEM and non-STEM learning environments via presentations, communications, time management, and teamwork activities. Participants in FG#3 and FG#4 stated that the educators were taking steps to not force or over-propagandize the STEM agenda in a way that could disengage interest; rather, they were attempting to create the conditions for students to naturally gravitate to STEM by raising awareness of the possibilities, empowering independent choice, and adopting an entrepreneurial risk mindset (for instance, through Career Exploration classes). The approach was believed to be able to help broaden or amplify STEM engagement and build students’ self-confidence, self-decision capacity, and self-efficacy in pursuing their personal interests, said several participants in FG#4.
Participants in FG#4 also stated that ESM High School offered an eclectic array of STEM classes and non-STEM electives through their Spartan Academy portfolio albeit, the myriad choices were found to be confusing and overwhelming for students due to a combination of nonoptimal marketing and conflicting schedules. Identified was the need to improve the structuring, marketing, and implementation of a STEAM curriculum, which had been loosely federated at best, to guide the students on a path towards their higher education and career interests. Cross-disciplinary coordination and support had been called for that would bridge seemingly disparate domains as a way of expanding frames of thought and creating new opportunities to fill the gap.

Participants in FG#4 added that ESM High School had successfully connected their STEM education programs with industry and business workplaces. In fact, the connection had been enabled by the school’s STEM program itself. An effort had been underway to reduce STEM intimidation and dispel the notion of STEM as a pursuit reserved for the elite. Overcoming the stereotype myths about the rigors and demands of STEM fields compared to non-STEM fields was also considered important in filling the gap. The stereotype questioned the worthiness of STEM pursuits compared to the many non-STEM opportunities that had been advertised as equally, if not more rewarding, high-paying, and less-demanding, thus sending a biased message and giving a false impression of STEM. Furthermore, it was recommended that views on STEM should be recalibrated to be inclusive of technical vocation/trade jobs.

Participants in FG#6 commented that today’s broad definition of integrated STEM compared to the traditional, siloed notion of STEM of the past indirectly gives rise to another gap. The idea of integrated STEM, which was notional in the past, has come
to fruition today, but it is far from being a practicable model. A gap in understanding what constitutes a STEM field or pursuit has existed across the multidisciplinary landscape begging the question, “Is today’s integrated STEM strictly a college/university or professional pursuit, or can it encompass vocational/trade pursuits?”

Today’s college STEM push has disenfranchised those in pursuit of technical vocational/trade jobs, said participants in FG#6. The technical trades have often been interpreted by many as being “outside” of STEM because they are not a degreed or diploma-based program, although one can receive a professional certification. On the other hand, STEM has drawn on multiple disciplines rooted in the technical trades (for example, electrical, mechanical, carpentry, construction, and so on). Ignoring the trades had been felt to diminish STEM’s full potential.

A strong demand exists for high-paying STEM trade apprenticeships and jobs. Many students have expressed an interest in STEM trade pursuits; although, influencers from within academia and elsewhere have attempted to steer them away from the vocational trades and instead follow a college-bound path. Hence, according to participants in FG#6, a “tension” at ESM High School had existed in enabling a student’s free and fair informed choice regarding a career path based on their own individual interests.

Next, participants in FG#4 called for teachers, school counselors, and school administration to place a high priority on cultural values aimed at teaching students how to embrace multiple perspectives regarding their career pursuits. Such guidance would balance personal interests and salary expectations against risk and reward, job availability/demand, contributing to society and humanitarian needs, hard work ethic, and
other benefits. The approach would help fill the gap by taking steps to preclude an underprepared future STEM workforce.

Additionally, several of the FG#4 participants felt that ESM High School had been somewhat successful in hosting resident career education services instead of outsourcing them, such as their resident Career and Technical Education (CTE) classes. Doing so would be convenient for students and would build capacity within the school to internally expand its offerings. Similarly, ESM High School had participated in STEM-related teacher-exchange programs (for example, in aviation) which outside institutions have considered adopting.

Teacher staffing remained another challenge though. For every novel idea proposed or put into practice, the teachers were expected by the school administration to either take on the extra work or sacrifice another initiative (one of the FG#4 participants stated, “One new shiny program can hurt another existing program.”). Consequently, teachers had willingly added to their workload when possible, but a saturation point could occur once the weekly schedule became too dense. Teachers’ focus and time have also been redirected. They had spent less time delivering content because of the distractions in coping with some students’ familial, behavioral, and emotional issues in the classroom. In effect, the teachers had taken on greater roles and responsibilities in areas that were traditionally shared by others. The problem had been driven in part by budget factors.

A “massively systemic” dysfunctionality was cited by several of the FG#6 participants that originated at the federal and state levels. According to them, current educational legislation, standards, and thought leadership have been “bulky and bloated” and trickle-down policy has built-in obsolescence fostering a too little, too late response
to technology and other scholastic STEM needs that have superseded the original requests. The lack of resources and the delivery of outdated content and standards-based teaching protocols placed teachers at a disadvantage. Because of a burdensome institutional and legislative process, teachers have been hampered and students’ progress and chances for advancement stymied. In effect, the process had been unfair to teachers and an injustice to students. According to participants in FG#6, the urgency for skill set development in critical needs areas has been bogged down by the inertia of the “system” or the “bureaucratic red tape.”

Next, the FG#6 participants focused on how technology had permeated STEM classroom education and throughout the entire school system. Computers and other types of digital technology indeed provided advantages for STEM learning to help bridge the “digital divide.” However, the potential disadvantages included an over-reliance on technology as a “crutch” in critical problem-solving tasks that had “diluted” the students’ critical and independent thinking processes. All access to too much technology at virtually anytime and anyplace was not always considered a benefit.

All factors considered, the FG#3 and FG#4 participants felt that ESM High School had established itself apart from other CNY schools by having the core of a unique, progressive STEM program that integrated art electives but on a case-by-case basis. The program sought cross-disciplinary connections, engendered critical thinking, promoted problem-solving within real-world contexts, and supported career and technical education classes that had become a model for other CNY schools to follow. Although, some areas of improvement had been cited. Nonetheless, ESM High School had taken steps to fill the STEM gap but continues to face ongoing challenges to expand its existing
STEM programs and initiatives. The most fundamental challenges distilled down to (a) the “inflexibilities” due to the state education standards and the bureaucracies of the state legislative process, and (b) the lack of school career counseling that has now fallen more on the shoulders of the educators. The next section further examines the pedagogical gaps that exist and how today’s STEM initiatives address the above issues and concerns regarding sustained engagement.

Present STEM pedagogical gaps. The educator focus groups offered a cogent and compelling argument on the role that the STEM curriculum played in STEM engagement and persistence. The curriculum consisted of content, lesson plans, activity structures, delivery methods, and a conducive STEM learning environment or setting that highlighted teacher engagement. The current focus group question asks, “How does today’s STEM curriculum/agenda affect engagement and persistence and do gaps exist?” The question was a follow-up to the previous one that compared the educators’ past and present STEM experience. This focus group question examined in depth today’s curriculum-based strategies and whether the strategies had been effective in cultivating STEM engagement and persistence or if additional interventions should be considered.

The ESM High School STEM curriculum was thought to be highly constrained by state education standards, guidelines, and policy-driven practices all contributing to the gap. The study underscored the need for implementing a progressive STEM learning approach that exploited multidisciplinary synergies and practical contexts. ESM High School had put into practice certain measures that opened the door to an integrated, interactive, multidisciplinary STEAM learning via PBL and other complementary approaches. However, a comprehensive rollout awaited a reformation of STEM program
policies, procedures, and recommended practices at the state level in the future. A synthesis of the teacher focus group feedback that touches on the above themes towards STEM curriculum reform is presented next. The discussion highlights the state of the ESM High School STEM curriculum, the gaps that exist, and additional strategies to increase STEM engagement from the teachers’ perspectives.

To begin, according to nearly everyone across the focus groups, siloed STEM learning environments persisted at ESM High School—a legacy of outdated practices, although exceptions were cited. ESM High School was in the process of a “middle mile” transition between siloed STEM learning and a more progressive STEAM format although, the school was in the early stage of transition. Most of the FG#3, FG#4, and FG#6 participants shared the general belief that a STEM engagement issue existed, but that it was less about developing strategies to engage students in STEM and more about the ability to implement such strategies.

Several of the FG#4 participants firmly believed that the teachers were passionate about their jobs, cared for their students, considered themselves catalysts in promoting STEM engagement, and had earned their students’ respect in the process. The teachers felt that they were well positioned to lead efforts in promoting STEM engagement. Barriers arose that limited their ability to make novel strategies actionable by turning ideas into programs, thus unveiling new gaps. According to the FG#3 participants, their efforts have been largely plagued by circumstantial factors as explained next. The following barriers and associated gaps were cited across the focus groups and are listed in no order of priority:
• Difficulty in breaking down legacy, siloed learning structures constrained by NYSED testing regulations and institutional frameworks driven to meet accountability and regional assessment standards;

• Institutional inertia coupled with staff logistical and time constraints that limited progress in implementing multidisciplinary, application-based curricular models meant to assure continuity in experience from high school to post-graduation;

• Communications and marketing that non-optimally advertised STEM offerings coupled with a wide array of options that confused and overwhelmed students;

• Disenfranchising those interested in STEM vocational trades from mainstream STEM opportunities;

• School counselors unprepared to provide informed guidance regarding college, professional, and vocational/trade STEM career paths and opportunities;

• Lack of support for students in confronting real-world challenges, making informed decisions, and culturing them to embrace and recover from failure;

• Inspiring a culture of curiosity and the practice of inquiry beyond that found in the NYSED’s Next Generation Science Standards (NGSS)—teaching students to ask (the right) questions and adopt a risk and reward mindset; and

• Managing the distractions of technology that can reduce attention span (for example, students frequently using social media in the classroom).
A set of recommendations was offered to fill some of the gaps and enhance the STEM learning experience and engagement outcomes. The recommendations, as a synthesis of ideas across all focus groups, were aimed at STEM students who, academically speaking, were on the border line or were unsure of their interest in STEM, rather than on students who regardless, were firmly ensconced in either the STEM or non-STEM camps. However, the recommendations were also aimed at students with a high STEM affinity to reinforce their post-graduation STEM persistence. The recommendations, in no preferred order, included:

- Providing exposure to real-world problem-solving opportunities (Capstone project, for example) inside and outside the classroom;
- Enabling the students to make informed choices through proper guidance;
- Showing the students how they can be agents of change;
- Cultivating an institutional growth mindset via entrepreneurial principles;
- Raising awareness of faculty attitudes and expectations and developing mutual trust between faculty and students to foster interest and elicit constructive feedback for positive change;
- Understanding or measuring lesson effectiveness or impact;
- Providing support as needed to address the students’ weaknesses, then reassess and verify acquired skills, and progress rather than use a monolithic, linear, or “one and done” approach;
- Making meaningful multidisciplinary connections (synergies);
- Replacing standards competency-based pedagogy with application- and outcome-based models in which students learn by directly engaging in
applying theories, models, tools, and skills to meet specific goals and that allow outcomes to be measured, to bridge the high school and post-secondary experience;

- Ensuring *continuity* in learning and understanding multidisciplinary synergies (thematic threading), setting realistic goals, encouraging experimentation, and *powering* through failure to prevent disengagement when entering college or the workforce;

- Informing high school counselors of the importance of inclusivity and fairness in promoting both college and vocational trade STEM opportunities by weighing interests against job demand, personal investment, salary, scholarships or tuition assistance, and other tangible or intangible factors in career path decisions;

- Crystallizing the messaging and marketing/advertising strategies to raise the students’ awareness and lower their confusion or anxiety about the spectrum of class offerings and activities while incorporating scheduling flexibility;

- Actively reaching out to students to engage them in STEM to build interest and show the paths toward academic and post-secondary career opportunities;

- Informing parents and families of STEM options for 2- or 4-year colleges, vocational trades, scholarships, internships, job markets and timelines, and associated risks/benefits (ESM High School had shown success here);

- Recruiting industry experts to provide practical STEM education and training experience to both teachers and students and developing new courses with creative content; and
Fostering an integrated product team mentality early on for team building.

Participants in FG#6 further recommended that the teachers should show how STEM and certain non-STEM classes are connected and illustrate their interdisciplinary nature using concrete examples or practical problem sets. Their FG#4 counterparts further supported the integration of English, arts, and the humanities into STEM to improve verbal and written communication skills among other reasons—an argument for extending STEM into STEAM. Also, several of the FG#6 participants stated that a content driving curiosity pedagogical approach was advantageous over simply explaining how and why something is important. The next section examines ideas on content delivery and curiosity in the context of creativity and how creative learning environments may contribute to increased STEM engagement.

Creative learning environments. Creativity is paramount to an effective and impactful STEM curriculum. A creative learning environment that promotes experimentation using engineering and design for instance, is known to spark innovation and discovery. The question asked here is, “How could creative learning environments further stimulate an increase in STEM engagement?” The question probed how creative approaches can be introduced into STEM learning to help increase interest and engagement that could lead to rewarding STEM careers where competitive research, development, innovation, and discovery that positively impacts society can be realized.

Creativity was viewed by the focus group participants through a scientific lens which defined the components of STEM as the tools to achieve creative processes. STEM was thought to enable creativity by adapting the arts and mimicking creative processes such as science communication through coherent written and verbal
expression, using improvisation to convey concepts in colloquial or readily understandable terms, applying artistic design to complex structures, and so forth. Anecdotal accounts were given of people who were known to have attended classes that integrated artificial intelligence, society and humanity, and literature attesting to the merit of creative, multidisciplinary learning environments.

Participants in FG#4 believed that creativity was at the root of successful business models and profitable companies. The participants offered compelling metaphors such as Apple, Inc. which incorporated aesthetically pleasing and functionally ergonomic designs in its products. Other metaphors were the engineer who becomes a clock maker; the saw as a tool used in constructing a piece of furniture (functional engineering) and then using a router and lathe to create perfect edges and contours (artistic form or design); the architect who routinely integrates engineering and artistic design to visually convey ideas; and using English literature as a tool to set up the “technical” sentence structure and letters where it comes down to the beauty of creative prose and storytelling. The point here was that without the “soul” of the art, only “bare technicality” remains.

Teacher participants from FG#4 and FG#6 were pleased that students were able to demonstrate a capacity to embrace non-STEM subject matter in STEM class projects. Music, however, was never explicitly mentioned as part of the creative tool set for any aspect of STEM learning or engagement by any of the focus group participants. The FG#4 and FG#6 participants said that ESM High School had some latitude in introducing creative ways of teaching STEM subjects within reasonable and practical limits.

On the other hand, several participants in FG#4 added that as with all Central New York schools, care must be exercised to avoid risky programs that might be out of
scope to NYSED’s requirements and that could jeopardize STEM education grant funding. Their responses were largely in the spirit of cautiously implementing integrated, multidisciplinary STEM-type programs. The next section further addresses how and why integrated STEM learning could be beneficial to STEM engagement.

**Integrated vs. siloed learning benefits.** The question here is, “How or why could integrated STEM learning be beneficial?” The concept of integrated STEM learning embodies two fundamental meanings. One meaning refers to gaining an understanding of the interrelationship or interconnection between the individual STEM subjects to develop a comprehensive, efficient set of tools or skills for practical problem-solving; the second connotation refers to integrating other non-STEM disciplines to enhance the STEM learning experience.

In either case, integrated STEM resolves into a multidisciplinary learning strategy or an interdisciplinary pedagogical framework. It has been conjectured that an integrated, multidisciplinary approach may stimulate interest in STEM by exposing its deep, multifaceted nature to exploit opportunities for innovation and design. The question focused on the potential benefits of integrating or interconnecting the individual components of STEM and certain non-STEM subjects within a pedagogical framework over the use of a siloed learning structure.

The participants across all the focus groups generally agreed that siloed teaching was still prevalent at the high school level, confirming earlier study findings. According to several participants in FG#3 however, the culture had changed at ESM Middle School where more of an integrated, multidisciplinary STEM learning protocol was in use. The inconsistency reflected a difference in the way the NYSED standards had been applied.
that created a discontinuity in the STEM program across the grades. Implementing change at the high school level had consequently been challenging, slow to unfold, and somewhat limited in scope and impact. Participants in FG#3, FG#4, and FG#6 concurred that the overarching state education bureaucracy (“the system”) was largely to blame.

The system, by default, had fostered a siloed STEM learning mindset yet pointed to the need for a progressive curriculum that embraced integrated, multidisciplinary learning and creative lesson planning. The dichotomous messaging and policies led to STEM programs that were implemented nonuniformly or disjointly. The regional and district constraints on the STEM programs were a result of meeting the state standards for curriculum and content delivery, testing and grading, and teacher assessments. The dichotomy had forced high school STEM teachers to approach change in a cautionary way to preclude risks, although they had experimented with ways to cross-fertilize knowledge across different domains for the benefit of their students.

Participants from FG#4 stated that the ESM teachers had internally discussed possible approaches to overcome siloed STEM learning by leveraging ideas from university Capstone and Project Lead the Way initiatives (Project Lead the Way, Inc., 2019). The ESM teachers had attempted to make a gradual shift to a more integrated curriculum at least 1 day a week by hosting the math, science, and English teachers together in the classroom, although incorporating the math had been problematic.

Several of the FG#4 participants suggested the strategy could also include sponsoring specialty topics and guest instructors (in cosmetology, avionics, construction, automotive, financial management, career training, forensics, and a host of other topics); multidisciplinary skill sets, tools, and applications would be presented or demonstrated
under this format. The strategy would expand the students’ knowledge and understanding by building on their prior math, science, and English education.

Additionally, participants in FG#4 stated that larger group sizes were preferred over smaller groups, although neither was defined or quantified. Large groups offered important advantages along a range of dimensions. For instance, they facilitated expanded conversation, brainstorming, teamwork or interactive collaboration, multifaceted problem-solving and shared (authentic) learning, productive behavior and engagement, and the refinement of skill sets. Some disagreement was noted between FG#3 and FG#4 participants on the overall merits of small versus large group sizes. The small groups tended to be more limited along the above dimensions and virtually absent altogether in siloed settings. Again, none of the focus groups quantified what large versus small group sizes meant. The group size issue was not brought up by any of the FG#6 participants.

According to several of the FG#3 and FG#4 participants, the ESM teachers had explored the formation of multidisciplinary teams to synergize non-STEM subjects like English to improve science communications (reading, writing, and verbal skills). Math, however, was found to be more difficult to include due to the inability to synchronize math teachers’ schedules along with curriculum constraints or other priorities and because of a lack of defined goals. Again, the constraints on the curriculum had forced teachers to focus on meeting the state education standards regarding testing, test scores, and teacher assessments, instead of pursuing novel STEM programs.

An anticipated shift would be towards applying literacy and critical thinking-based methods for STEM, which participants in FG#3 and FG#4 thought was a proper
step to take. The FG#3 participants cited a Mars Rover Project as an example of the shift which had brought together teacher and student groups for collaborative deep learning experiences, open inquiry-based learning, and where the individual STEM subjects were tightly interwoven to spark multidisciplinary conversations for effective outcomes. The FG#3 and FG#4 participants generally felt that a further shift would be needed by eliminating regional testing altogether.

Several of the FG#4 and FG#6 participants highlighted the challenges of teachers staying current with and grasping the rapidly changing, eclectic content to pave the way for integrated, multidisciplinary STEM learning; indeed, past tools and methods rapidly become obsolete in the modern, fast-paced technological world. Teachers will need to acquire new skills and be well versed in multiple subjects; alternatively, specialists and outside experts could be recruited to help shape the new STEM pedagogical landscape.

A “common planning” tool was envisioned by several of the FG#4 participants to preclude interdepartmental “disjointedness” and to be more cohesive, cooperative, and better coordinated on behalf of achieving STEM goals. However, past efforts to develop joint curricula, lesson plans, and project decks for this purpose had been challenging. Examples of past initiatives and committees that were formed to help shape progressive STEM programs at ESM High School included the 21st C Learning Committee that eventually became the PBL Committee (emphasizing technology and team-based learning), followed by Project X (modeled after Syracuse University’s Project Advance), and the Innovation Studio (a progenitor STEAM program). The latter programs at the high school level attempted to focus on multiple PBL activities coincident with each marking period. Time was reserved at the end of each class for independent (siloed)
research followed by a group PBL activity for knowledge discovery and sharing. Participants in FG#4 offered the example of a car crash forensic study that brought together individual perspectives on the math, physics, and other disciplines to ultimately solve a problem in a team setting.

Marketing, public relations, and messaging were also identified by FG#4 participants as key factors in any successful STEM or STEAM program rollout. Success on these fronts was predicated on informed school counselors who can share the STEM vision and articulate the possibilities, options, and opportunities to students and their parents or mentors to secure STEM engagement. A positive step would be for teachers and counselors to work together on incorporating career training and internship themes into existing classes instead of conducting a separate class on those themes to make stronger, more direct connections. However, the idea also had not been adopted or put into practice and participants in FG#3 and FG#4 had expressed disappointment in the lack of follow through on this and similar fronts.

One of the FG#6 participants emphatically expressed opposition to conducting the “standard” projects in class. The participant, as a teacher, stated that a complementary engagement strategy, in lieu of conducting standard class projects, was to exploit self-motivational theories to stimulate one’s creative potential. Particularly, Maslow’s psychological contract motivation and needs theory was applied, which taps into human self-motivation to achieve higher needs by first satisfying one’s most basic needs (Gambrel & Cianci, 2003; Maslow, 1965; Paul, Niehoff, & Turnley, 2000). It asks the question, “What influences one to make decisions in their own way?” Maslow’s theory is depicted in Figure 4.2. The figure shows how pinnacle self-actualization is achieved
by progressively satisfying aspirational goals starting with one’s most basic psychological needs and migrating upwards to satisfy higher and more complex needs.

In the Maslow approach used here, rhetorical devices and traditional literary or historical references were introduced using the framework shown in Figure 4.2 to specify relationships across various concepts including STEM. The relationships were combined to establish new, creative learning spaces to solve a problem; it is likened to an integrative, interdisciplinary STEAM approach for practical problem solving. An example was given of a boardgame designer collaborating with a tabletop game designer to create new kinds of simulations that emotionally engage the player at multiple levels; the embedded literary elements and/or historical contexts provide a means of learning literary and historical lessons through a gaming lens and where the design challenges
draw on math, computer science, and graphic arts to establish new, creative learning spaces. The discussion set the stage for the next focus group question that explored other connections and creative learning spaces that combined STEM and the fine arts namely music, including progressive pedagogical strategies.

*Non-STEM (fine arts) connections.* The question asked here is, “Do you believe that STEM and the fine arts (for example, music) are interconnected, or should the subjects be taught entirely in isolation? Explain.” STEM pedagogy appears to be slowing trending away from the traditional, siloed learning approaches of the past yet integrated, multidisciplinary STEM-based learning is far from commonplace in today’s schools. Notwithstanding, efforts have been made to engage students in STEM through non-STEM connections such as the fine arts; although, the attempts have been experimental, speculative, partially implemented, and have met with limited success. Infusing selected aspects of the fine arts into STEM has been more of the exception than the rule. The question examined the participants’ experiences in introducing fine arts connections to STEM focusing on music, and to determine if there were reverse benefits from STEM to non-STEM fields, although the latter was of less interest for the purposes of the study.

The following viewpoints, synthesized across the three educator focus groups, were offered in response to the focus group question: (a) avoid forcing the fine arts like music into the STEM curriculum unless a reason exists (for example, relating the *art of music* to the *science/physics/math of sound* would make perfect sense); (b) focus on other non-STEM categories such as artistic color schema and tools to examine for instance, the synergies between fashion and materials technology and design; (c) embrace the idea of
music in STEM while acknowledging the barriers that exist (state education standards and teacher time constraints) that limit experimentation and delay curriculum reform; (d) unconditionally change the STEM curriculum to integrate music and the other fine arts; (e) exploit the notion that those who are music oriented tend to be math/science oriented; and (f) use music “immersion” as a tool to stimulate creativity in the STEM learning process and heighten the effectiveness of STEM multimedia content delivery.

Categories 3-5 above were the dominant viewpoints expressed mainly by participants in FG#3 and FG#4. Whereas the FG#3 and FG#6 participants were supportive of incorporating music into STEM, participants in FG#4 seemed opposed to the idea unless there was a specific reason or purpose to do so. The counterpoint made by participants in FG#4 and FG#3 on not forcing music in STEM was meant to avoid any unnecessary or artificial intersection of the two for the purpose of notionally implying STEAM, where some have interpreted such an intersection as an attempt to “dilute” STEM’s impact. An unintended consequence could be where some perceive the replacement of the “M” for “Math” in STEM with “M” for “Music.”

Drawing on their personal experience as musicians and STEM teachers, several of the FG#3 and FG#4 participants likened the ability of playing musical instruments and performing in an orchestra to conducting individual STEM research and engaging in a STEM group problem-solving activity. Indeed, orchestra, band, and chorus teach one how to work both independently and groupwise and to think critically and efficiently. Several participants in FG#3 agreed with the analogy. An FG#6 participant asked the question, "What was the most important thing that one did in high school that prepared them for their job or career today?" The question prompted a realization by the group on
the importance of applying novel methods, like music-based interventions, to stimulate creative independent/team learning and critical thinking as part of a progressive STEM curriculum. Several of the FG#6 participants were highly enthusiastic on that point.

Also, mathematics and music were thought to be strongly connected according to several of the FG#3 and FG#4 participants (for instance, the Fibonacci series also called the Golden Ratio or “God’s fingerprint” has often been used in music composition). The positive influences on left/right brain development, learning capacity through association, and creativity were cited. Other fine arts like theatre, role playing, and improvisation were also identified as effective tools for science communications, embracing multiple perspectives and comprehending diverse frames of thought, self-expression, and confidence-building. Participants in FG#4 and FG#6 shared a positive view of music as a gateway to other fine arts and humanities (for example, history, English literature, and stage production acoustics and lighting) that intersect well with STEM to provide for new and rich contexts.

Several participants in FG#6 noted that gaps have arisen in introducing the fine arts into STEM because of the state education standards. Specifically, the constraints imposed by the state education standards and the limited time to develop and test content were viewed as significant barriers to a progressive STEM plus arts program rollout. Notwithstanding, the STEM teachers were able to conduct some cross-disciplinary classes.

Although most of the participants were hopeful of the intersection of the fine arts like music and the STEM curriculum, they were disappointed in the lag and lack of progressive planning on this front. Most of the participants across the three focus groups
were also discouraged by a general unpreparedness to fully commit to expeditious planning on a broader scale for the students’ benefit. Additionally, it was believed that the longer it takes to expand STEM programs in this way, the more the students will be shortchanged, and the greater will be the STEM attrition rate. The discussions led to a more focused examination of music as a possible enabler for STEM engagement as discussed next.

*Music stimulating engagement/persistence.* Some experimental approaches have examined the role music plays in increasing STEM interest. Music is worthy of study from both a STEM and an arts perspective lending to an adage, *the art of music and the language of mathematics to the science of sound.* The questions posed is, “How might non-STEM subjects like music enhance STEM engagement/persistence?” The question further extended the thought leadership discussion on “how” STEM engagement and persistence are heightened through the introduction of fine arts or non-STEM subjects like music. The perspectives of the teacher focus groups on this question are explored next.

Participants across FG#3, FG#4, and FG#6 were split on the efficacy of non-STEM subjects like music offering benefits to STEM engagement and persistence. Nonetheless, most of the participants across the three teacher focus groups believed that music can significantly benefit STEM learning and engagement. The results corroborated the findings of the previous focus group question. However, many of the participants were much more concerned about how STEM was defined and called into question the effectiveness of today’s outreach tactics and their impacts on long-term engagement. The aggregate responses were categorized along the following dimensions:
a. A strong belief in the complementary nature of STEM and music, particularly the field of mathematics, and the overall benefits on STEM engagement;
b. STEM’s aim citing past ill-conceived strategies that resulted in disengagement (for example, switching from a STEM to a non-STEM field of study);
c. How external factors influenced STEM persistence such as risk versus reward, expectations and demands, stress or anxiety, and negative outcomes especially in the case of students with low STEM affinity pipelined into a STEM field;
d. Uncertainty vis-a-vis personal interests versus career trajectory in view of professional versus trade/vocational STEM career pathways;
e. The “reverse” effect of STEM engaging interest in non-STEM careers; and
f. Enabling students to make their own academic and professional career choices while building on their outside interests.

Most of the participants in FG#3 and FG#6 agreed that music positively benefitted STEM engagement because of how the art and science of music could be related in an enjoyable and thought-provoking way with math at the center of the relationship. The participants felt that the two domains shared core problem solving and critical thinking strategies; for example, individual research in one or more STEM fields was analogous to practicing a solo piece in music, and a STEM group-based problem-solving activity was likened to preparing an orchestral music piece. A similar analogy was offered by one of the participants during a prior focus group segment that explored aspects of the fine arts on STEM engagement. On the other hand, it was unclear to many participants in FG#4 what today’s STEM goals were aiming to accomplish regardless of including non-STEM subjects like music.
Next, several FG#6 participants commented on the “reverse STEM effect” in which STEM-disposed individuals aspired to non-STEM fields such as music. Examples from personal experience were offered in which interests in music were amplified by exposure to related topics in STEAM. Indeed, STEAM provided a platform for envisioning the interplay of the musical notes, time signatures, and rhythmic patterns rooted in mathematics and science and that are resonant with the creative process.

Furthermore, according to participants in FG#6, although the teachers were open to and supported the idea of cross-disciplinary curricula that integrated STEM and certain non-STEM subjects like music in class offerings, it could only be done on a restricted basis. Again, this was due to the limitations of the state education standards, academic resources, and personal available time. The next section examines a totally different aspect of STEM learning beyond the non-STEM component influence, which is related to learning modalities and environmental characteristics.

**Effective learning modalities.** The question asked here is, “How do students learn best (tactilely, visually, small group collaboration, other)?” The question explored ways that classroom learning modalities could stimulate STEM learning and engagement. The potential relationship between STEM learning capacity and music-inspired or auditory-based learning was of specific interest. The level of STEM interest and the rate of STEM learning are fundamentally dependent on the student’s ability to assimilate information that is of interest to them. People have different learning styles and there are many factors at play. There is no single modality that will consistently work for every person or in every case and there are different “parts” to the learning process. How one learns is dependent on his/her individual interests; outside (teacher/mentor, peer, and family
member) influences; whether the environment is conducive to learning; and how the environment structures, engages, or incentivizes learning in terms of degree of rigor, defined project goals, test score and grade measures, and alternative approaches that allow for the freedom to explore. Other factors include group size and if the learning environment is sufficiently challenging, thought-provoking, and curiosity seeking.

The participants across the three teacher focus groups generally agreed on multimedia content delivery as an optimal approach. Multimedia means a combination of visual, tactile (hands-on), auditory, and experiential learning that exposes students to real-world problem-solving sets. From the standpoint of individual learning, the top three modalities identified, in order of priority, were visual, tactile, and experiential (learning by watching, doing, and trial and error repetitive application). Kinesiology learning was also identified as a potential modality by an FG#6 participant.

On the other hand, auditory learning, including the use of music or sound as a tool for increasing STEM learning capacity, was not identified as a priority learning modality by any of the focus group participants; although, naturally developing good listening and verbal communication skills amidst lectures or discussions (showing, telling, and explaining) was considered important. The finding, however, did not explicitly support the Chapter 2 research on leveraging music as an art form to stimulate STEM engagement. It is important to note that music was offered as an elective for STEM and non-STEM students at ESM High School; music has been loosely integrated into the STEM curriculum, but its impact has not been thoroughly studied or tested, opening an avenue for future research.
To reiterate, the learning modality of choice is student dependent with no single, preferred technique thought to always work best for everyone in every given situation. Several of the FG#3 participants suggested taking the time daily to reflect on and assess how classroom tasks were accomplished and content learned with and without the addition of stimuli such as music to track the different levels of knowledge discovery or understanding and rates of learning. Practical, hands-on experience was nonetheless frequently cited by the FG#3, FG#4, and FG#6 participants as a “learning modality” that is effective in “surfacing” a student’s abilities and reinforcing positive outcomes.

Additionally, several of the participants in FG#4 and FG#6 cited the conduciveness of the pedagogical environment or classroom setting to STEM learning as another type of modality. Specifically, group/team collaboration and group size dynamics were addressed in this context. Although the participants did not dispute the overall merits of collaborative group learning, there was a significant divergence of opinions from within FG#3 on the efficacy of group interactions at the high school level.

Several of the FG#3 participants considered team/group collaboration unfeasible, awkward, and not able to produce the desired outcomes. Small groups were especially found to be problematic and produced less-desirable outcomes than did larger groups. The reason for this was uncertain, although participants in FG#4 cited factors such as soft skills gaps, particularly gaps in interpersonal communications skills, exacerbated by an overuse of or overdependence on social media platforms for daily communications. Small groups tended to limit brainstorming and generating new ideas, lacked diversity in perspectives, and often prematurely converged towards agreement or consensus without necessarily considering all possible views. On the other hand, larger group dynamics
produced better outcomes allowing for more independent, self-expressive frames of thought to unfold that “snowballed” into natural conversations and lively point/counterpoint dialogue.

A somewhat different perspective was offered from within FG#4 regarding small groups. It was stated that although the small group mindset can be problematic, that could change if strong, independent thinkers were in the group who were unafraid to express themselves or their beliefs coupled with more hands-on (learn by “doing”) opportunities. To address the group interaction issue, a progressive strategy to augment current learning modalities was proposed for enhancing STEM learning and engagement. The approach was to progressively build on a teamwork culture that employers seek in support of industry integrated product teams and that underscored the importance of developing effective soft skills. The proposed strategy, reflecting a synthesis of modality-based ideas across the three focus groups, consisted of the following recommendations:

a. To establish a foundation, teachers should present students with a problem to be solved, exposing everyone to the same material in as many ways as possible (visual, tactile, virtual, and so forth);

b. Teachers should cultivate deeper learning experiences through early brainstorming and by guiding students’ thinking on cross-disciplinary connections and problem-solving strategies;

c. Students should be allowed to work individually at first to formulate ideas and concepts using modalities of choice;
d. Students should socialize ideas with one another either in a one-to-one setting or a selected, small group brainstorming session to solicit feedback;

e. Students should socialize refined ideas within larger groups; and

f. Students and teachers should participate in a variety of exercises and activities (presentations, for example) for deeper learning and understanding to emerge.

One of the FG#4 participants recounted a situation where a shift was made from traditional rote learning to real-world, project-based learning. The students scored better on exams because of the shift. Then NYSED made changes to the assessment process and included industry inputs on the exam. The students scored poorly highlighting the problem of basing success or failure on state test scores.

Participants in FG#4 provided several key recommendations to further extend the concept of STEM learning environments as a modality. It was suggested that the teachers should guide students in building an academic and experiential portfolio highlighting real-world and hands-on project experience, practical training credentials and certifications (for example, CISCO training), college preparation courses taken, and so forth without having to emphasize state test scores. It would be about exposing the person and his/her accomplishments and their potential for growth, success, and achievement instead of emphasizing test scores and grades, which are not a true reflection of a student’s abilities. The aspects of academic rigor and passing advanced course tests or projects requiring master-level skills should be de-emphasized, leaving that to the colleges and perhaps the workplace to cultivate.

Several of the FG#4 participants also discussed the challenges of teaching classes of students across a spectrum of learning-disabled, behavioral, emotional, and other
categories. The teachers found ways to apply rigor using multimedia learning tools, but challenges have been encountered regarding test scoring, class grading, and experimenting with content. A variety of alternative learning approaches and modalities were warranted in such cases.

The next section examines the findings from the data analysis that were used to answer the third research question, RQ3. The question explored the factors that tended to erode STEM interest upon/after high school and that contributed to widening the STEM gap from both a student and an educator perspective. The perspectives and data findings are presented as follows.

Factors that tended to erode STEM interest upon/after high school: students’ and educators’ perspectives. RQ3 which asked, From the standpoint of students and educators, why might STEM persistence or sustained STEM interest upon/after high school graduation be on the decline? probed into the factors that could erode STEM interest upon or after high school and that contributed to the STEM gap widening over time. The findings for RQ3 constructed micro views of the student and educator perspectives as another step in arriving at a macro view understanding of the STEM gap problem. The results of the data analysis for the student- and educator-based focus groups are provided in Appendix F, Table F1 and Appendix G, Table G1, respectively, and are discussed in detail in the next section. The results for the student focus groups are presented first as follows.

Student focus group findings. The sections that follow will individually address the findings for the following five a priori dimensions: (a) sustaining interest, (b) pedagogical gaps and remedies, (c) math phobia, (d) female STEM
engagement/persistence, and (e) disadvantaged/underserved STEM engagement. These dimensions correspond to the next five student focus group questions (FQ8-FQ12) used to answer RQ3 and that were itemized in Appendix F, Table F1. The next section addresses sustaining interest from the student’s perspective and explores whether STEM interest at ESM High School decreased, plateaued, or was on the rise.

Sustaining interest. Whether a student’s STEM interest increased, decreased, or plateaued during their senior year can be traced back to the quality of the STEM program combined with their perceptions and experiences, and if expectations have been met or not. In FQ1, the students indicated that their STEM affinity, qualitatively speaking, was in the moderately strong to high range. Was this due to ESM High School’s Spartan Academy STEM Program or perhaps a combination of the program along with other factors? The compound focus group question asked here is, “Has your interest in STEM in high school decreased, leveled, or increased? How and why?” The focus group question probed into the issue by examining how and why the participants’ STEM experience at ESM High School affected their STEM affinity after having considered several other aspects of STEM learning that were covered in FQ1 through FQ7.

The responses to the focus group question were found to be somewhat mixed across the three student focus groups. Participants in FG#1 and FG#5 stated that their interest level in STEM had not changed whereas others thought it remained high (also inferring no significant change). Participants in FG#2 on the other hand, stated that their interest had waivered then increased. On average, it appeared that their interest level had plateaued generally trending towards the high interest side. For those participants who felt their interest had leveled (towards the high side) or had increased with sustained
interest attributed it to (a) ESM’s program diversity (considered a popular viewpoint); (b) positive teacher leadership; (c) motivational teaching styles (encouraging one to keep improving); (d) collaborative group settings that allowed for independent/individual study; (e) nurturing environments (the willingness of teachers to step in, interact, and assist both individual and group activities); (f) integrated curriculum; (g) exposure to practical problem solving and actual workplace settings (also considered popular); and (h) family upbringing and peer encouragement.

The FG#2 participants also discussed the importance of having opportunities to embrace and overcome challenges (a common theme) as part of the STEM character building process. Where interests waivered but had leveled on the high interest side, the reason for this was based on their eagerness to learn, their capacity for absorbing knowledge, and their rate of learning. Some of the participants were discouraged by their rate of learning, but with peer encouragement and over time, they had reached a “comfort” level with the STEM material. Reaching a comfort level gave them a confidence boost to seize upon opportunities and understand how to best fit into the STEM regime—all aspects of self-efficacy, self-realization, and increased self-awareness. Participants in FG#2 cited self-attitude as an important factor in STEM learning and engagement. Self-attitude referred to developing a positive disposition towards STEM, embracing and enjoying STEM challenges, maintaining one’s thirst for knowledge, and being open to accepting career guidance while exercising choice in navigating the “unknown” to further build confidence.

Corroborating the FQ1 data findings, the students generally identified themselves as more strongly STEM-disposed as opposed to arts/humanities-oriented from a career perspective.
Their STEM interests had increased, plateaued, and remained high owing to ESM’s programs that combined STEM and certain fine arts course content when possible. One of the FG#5 participants mentioned the use of creative displays, communication, and advertising in STEM competitions.

The next section will recanvas perspectives previously offered to sift out any known or perceived gaps in STEM learning that could negatively affect engagement and persistence. When answering several of the prior questions, many of the focus group participants explicitly identified or alluded to perceived gaps. The next section will attempt to highlight the primary pedagogical issues or concerns in STEM engagement and persistence from the participants’ perspectives.

*Pedagogical gaps and remedies.* STEM gaps in the present context refer to policies, procedures, practices, or methodologies that have either omitted certain enabling components and/or that created intended or unintended barriers to free and open STEM learning, engagement, and persistence. Some of the gaps may be traced to budgetary factors using risk-reward or cost-benefit analysis models that may or may not leverage validated bodies of knowledge or informed sources of information. Perhaps the best source of information to gain insight into the possible STEM gaps are the students themselves. Here the question is asked, “Do STEM education gaps exist and how could it be delivered more effectively for lasting effect?” The question examined the perspectives of student participants on the known or perceived STEM gaps that may exist and the ways to address them for increased STEM engagement and persistence. In examining the gaps and the ways to overcome them, the following was observed.
First, several gaps were identified. One gap was related to ESM High School’s marketing and advertising of its STEM offerings. According to participants in FG#1, the teachers were doing an effective job at STEM outreach. However, called out was the need for the school administration to implement a more robust outreach campaign to raise awareness of its STEM offerings targeting students internally including outside industries and institutions. The need to improve upon existing STEM outreach strategies and recruitment campaigns was at the heart of the issue.

Participants in both FG#1 and FG#2 cited a lack of awareness of STEM program offerings because of the way the school catalogues were published or posted online; for example, the business and fine arts classes were more prominently advertised than were the STEM classes. The STEM offerings were often “buried” or hard to find in the school’s catalogues and brochures, thus lessening STEM’s visibility. Both the FG#1 and FG#2 participants stated that the marketing and advertising had led to low signups, scheduling conflicts, and decisions to cancel or preempt certain STEM classes forcing students into less desirable options. The participants expressed much frustration by this outcome.

The FG#2 participants stated in fact, that the school-sponsored art events were better advertised than were the technology events, which has often caught the public and school members off guard. Participants in FG#2 added that the current marketing approach with its myriad choices of non-STEM offerings and conflicting schedules had “interrupted” the longitudinal continuity and flow of students’ STEM learning since middle school, which was believed to detract from sustainable STEM interest. Furthermore, it was recommended that STEM program marketing, advertising, and
outreach should be extended to the younger students. Using “STEAM” as an advertising strategy was cited by several FG#2 participants as a potentially effective remedy.

Participants from FG#1, FG#2, and FG#5 additionally suggested more practical, real-world or applied learning opportunities. Some FG#2 participants recommended that the school administration and teachers should launch a campaign to advertise an end-of-year, real-world project with defined goals to motivate students to get first-hand experience in practical problem-solving that could have lasting impact on STEM engagement. Several FG#2 participants further recommended arranging access to corporate facilities or natural laboratory settings to experience real-world problems and expand the students’ knowledge base. Several participants in FG#5 suggested deemphasizing rote (textbook) STEM learning and adapting a college-level mindset that emphasized applied learning. Another gap issue, the fear of mathematics and its effect on STEM engagement, is discussed next.

Math phobia. An apprehension of mathematics or math anxiety was suspected of contributing to STEM disengagement. Mathematics is considered by STEM enthusiasts to be the “glue” that binds the STEM subjects. One can conclude that an apprehension of math, as part of STEM learning, can isolate one from appreciating the many connections across the STEM disciplines and even across the non-STEM domains. The compound focus group question here is, “How do you feel about mathematics or the study the math?” Do you fear or embrace math? If fearful of math, how would you overcome it?” The question probed into the participants’ level of comfort with math and if fears existed, why, and what could be done to overcome them.
The responses across the participants from the three focus groups were mixed, ranging from no fear of math to having been intimidated by math, struggling with it, and overcoming the challenges of math as an aspect of STEM engagement and persistence. Most of the participants stated they liked math, felt comfortable with their math skills, and that it came to them naturally; although, several of the participants in FG#1 and FG#2 admitted to early math trepidation and had struggled with it at first but persevered and grasped it over time. A minority of students did not view math as one of their “favorite” subjects, although all the students believed that math was important in understanding real-world concepts and solving practical problems. Discussions were held with the groups about persevering to achieve an “a ha” moment with mathematics and why that was considered important in overcoming any fears.

Participants in FG#1 and FG#2 considered certain types of math more challenging than others and pointed out that the application of math was highly problem dependent. For instance, the domain or type of math had to be properly matched to relevant classes of problems and solution regimes. Participants in FG#5 believed that the fear was likely rooted in uncertainty, an accompanying anxiety, and second guessing oneself on the multiple approaches or methods that could be used to solve a given problem (Scholastic Aptitude Tests were cited as an illustration).

Participants in FG#1 cited teacher intervention as important in overcoming students’ math phobias. Participants in FG#5 suggested a rubric for overcoming the fear of math drawing on such interventions. The proposed approach was to abstract a complex problem by resolving it into smaller, simpler parts for a systematic treatment and then applying synthesis using logic steps to reconstructively solve the complete
problem. A successful synthesis depended on taking the proper steps in the right order which could itself be problematic, especially if a misstep occurred or if a step was skipped; admittedly, the latter could add to the uncertainty, anxiety, and fear in the end. However, the steps could be retraced to isolate errors, but it begs the question, “Can the math and the logic steps that one used be trusted?” Nonetheless, through a repeated application of the process to practical problem sets, one can gain a deeper understanding of mathematics’ role in STEM and beyond, to build one’s math skills and confidence—an experiential or lesson learned viewpoint.

To a large extent, the focus group participants felt that ESM High School had provided a positive environment for math learning as part of the STEM program, including ways to manage or overcome math phobias and build confidence. They identified the need for knowing how to apply the right kind of math to a given problem and how to approach complex problem-solving applications. A above rubric provided a foundation for students to develop the critical thinking skills and apply logic steps to solve complicated problems. Practical, real-world problem sets were recommended to see the connections more clearly across multidisciplinary subject domains and applications. In this way, the STEM students would better prepare themselves to meet the problem-solving challenges by building knowledge and confidence to allay any apprehension of mathematics. The thought was, by acquiring the knowledge and skills and building confidence, that STEM interest and engagement would naturally increase.

The next point of departure will be on the lack of female engagement as another STEM gap issue. The lack of females in STEM has been part of a much larger concern related to the disenfranchisement of underserved and disadvantaged groups. The next
section will tap into the student participants’ opinions regarding females’ views on entering the STEM fields and some of the barriers to entry they have faced.

*Female STEM engagement/persistence.* The present study was less concerned with conducting in-depth research into female STEM engagement except to identify factors that went previously undocumented and that could shed light on the STEM gap issue at hand. The question asked here is, “How do you think females view STEM as a college major or career choice?” The question builds on a well-documented body of knowledge on the relevant trends for females in STEM fields. Chapter 2 reviewed many of the factors that contributed to the disproportionate levels of female engagement in STEM fields. The question here was meant to identify other mitigating factors endemic to ESM High School that could expand an understanding of the trends and causalities.

This segment of the focus group activity had sought to identify trend reversals where engagement increased and the corresponding reasons for such. The focus group question raised several secondary questions and issues that were further explored below. For instance, did ESM High School implement measures or steps to enable females in STEM? From the students’ perspectives, what strategies had worked, and which ones had failed? Also, how did females view their own entry into STEM beyond high school?

To begin, the participants in each of the student focus groups immediately addressed the imbalance in the number of males and females in typical STEM classes at ESM High School. One participant in FG#2 estimated a 20% gender disparity in favor of males existed in STEM classes at ESM High School at the time of the study, which raised the follow-on question, “How had males perceived the ‘one girl in the room’?”

Generally, the males in FG#1 and FG#2 admitted to not noticing the gender disparity as
much as the females had experienced it; however, the disparity was acknowledged by virtually all the participants. Participants in FG#5 stated that societal “norms” and family upbringing were among the factors that contributed to the disparity, which nurtured stereotypical beliefs on the expected roles of males and females in society.

Although the situation had been slowly improving according to participants in FG#1 and FG#2, a significant gender gap persists. Participants across the three focus groups felt that until steps are taken to institute leadership, organizational, and policy changes to eliminate a “one size fits all” STEM strategy, the stereotype beliefs would continue. A synthesis of solutions offered by participants across the three focus groups included: (a) exposing females at a young age to STEM content, (b) marketing STEM to females but empowering them to make their own choices (not forcing them into a monolithic STEM program especially if they were less inclined to do so or not at all), and (c) supporting females’ decisions to split off into STEM and/or non-STEM classes and customizing the program to appeal to their specific interests as they age. The participants generally felt that ESM High School had successfully created opportunities for students to split off into STEM or non-STEM classes and customizing the classes and school experience to appeal to individual interests and professional career pursuits. In the words of one of the participants in FG#5, “One size does not fit all.”

The erroneous stereotypic belief that females were not well suited to STEM pursuits was something that would be difficult to change, according to the participants across all three focus groups. Participants in FG#1 and FG#2 cited a slow but evident culture shift towards increasing female participation especially in certain subset fields of STEM such as medicine, healthcare, medical technology, biology, and others. Also,
female participation has increased in STEM-related classes and electives such as automotive mechanics, avionics, construction, and civil engineering although their numbers remained relatively low. Certain STEAM classes that fused science and art aspects were the exception such as cosmetology (incorporating chemistry with the color wheel for chromatic blending), which brought in more female participation. Additionally, peer influence played a role in pipelining females toward STEM when they saw other females do the same, thus casting a “safety in numbers” net with the perception that it was “safe” to participate in a STEM activity or pursuit.

The discussion on how females perceived their engagement in STEM from the perspective of the participants led to a similar dialogue on disadvantaged and underserved groups that included women. For example, individuals who were socioeconomically disadvantaged could be denied opportunities to pursue a college STEM major or a high-paying STEM job. The next section will explore some of the factors that were identified and that could contribute to disengagement for these groups.

_Disadvantaged/underserved STEM engagement._ The question asked here is, “How could we better engage women, disadvantaged, or underserved groups in STEM?” The question built on the prior focus group discussions that examined the participants’ views on female engagement in STEM by considering other disadvantaged and underserved groups. Many of the issues identified for women also applied to outreach and capture efforts for virtually any disadvantaged or underserved groups. The general belief was that progress was being made on these fronts because communities of interest were aware of many of the relevant issues facing such groups, but that significantly more work was needed to address the issue.
Based on the discussions across the three focus groups, no clear, best strategy emerged to address the issue. However, participants in FG#1 and FG#2 proposed a possible way of filling the gap using a forward-thinking plan. The approach was based on democratizing STEM by offering a flexible and responsive plan that created opportunities and matched the specific interests and needs of these demographic groups in support of STEM career pursuits. The plan would be analogous to having a STEM college and career center at ESM High School, dedicated to serving underserved and disadvantaged groups. Participants in FG#2 expressed much interest in the concept of democratizing STEM.

Participants in FG#1 also proposed a customized STEM marketing and outreach program that was inclusive of disadvantaged and underserved groups and offered financial assistance or other incentives. Participants in FG#2 suggested that any plan should focus on career paths and strategies that were not purely driven by salary or economic stimulus and that dispelled any notion of STEM as aspirational—reserved for the elite; rather, it would stress self-improvement, advancement, and positive social contributions. Indeed, a similar plan to customize the STEM curriculum was proposed to assist females in STEM pursuits.

Participants in both FG#2 and FG#5 touched on a strategy to dispel gender, race, and socioeconomic stereotypes by focusing on aspiration versus situation; that is, encouraging one to seize the opportunity and exploit one’s potential to make a positive difference rather than dwell on socioeconomic woes or status. Paraphrasing one participant in FG#2, “It would be more challenging for disadvantaged or underserved groups to rise above the barriers to STEM career pathways.” The same participant added
that attempts to force the STEM agenda were ill-advised and would likely backfire; it would be more effective to nurture STEM engagement especially at a young age but to enable informed free choice. Again, the overall observations and recommendations here were found to be very similar to those previously presented on female self-perceptions in STEM engagement.

The participants were generally uncertain whether ESM High School had made any extraordinary attempts at STEM outreach to underserved or disadvantaged groups or if they had any success in engaging them. Based on ESM High School’s outreach aimed at females, efforts in support of underserved and disadvantaged groups appeared to be underway, although more work was necessary to realize positive outcomes. Indeed, certain steps would need to be taken via new policies, practices, and incentives for engaging underserved and disadvantaged groups. The results of the data analysis for the educator-based focus groups and how the findings answered RQ3 are discussed in the next section.

**Educator focus group findings.** The sections that follow will individually address the findings for the following five a priori dimensions: (a) STEM sustainability and persistence, (b) interventions/remedies, (c) math phobia, (d) female STEM engagement/persistence, and (e) disadvantaged/underserved STEM engagement. These dimensions correspond to the next five educator-based focus group questions (FQ8-FQ12) used to answer RQ3 and that are itemized in Appendix G, Table G1. The next section addresses the first dimension, a longitudinal view on sustaining STEM engagement drawing on the educators’ personal experiences and perspectives. The section qualitatively examined whether the participants’ experience with the ESM High
School STEM program had caused the students’ interests in STEM to decrease, increase, or plateau and to identify the contributing factors that affected STEM attitudes.

**STEM sustainability and persistence.** Although STEM has become a national and global priority, the number of STEM job placements tells a different story with troubling outcomes. U.S. federal statistics substantiate the deficiencies in STEM academic rankings and professional job placements. The joint question asked here is, “Has student interest in STEM in high school decreased, leveled, or increased? How and why?” The intent was to take a snapshot of ESM High School’s STEM program at the time of the study to gauge the students’ level of engagement from the teachers’ perspective. Furthermore, the question was meant to determine if any special STEM programs, interventions, or activities implemented by ESM High School resulted in any kind of marked change in overall STEM engagement during the students’ senior year.

According to several participants in FG#3, from the perspective of the teachers in the humanities or liberal arts studies, the students’ STEM interests were on the rise. On the other hand, from the perspective of teachers in the STEM fields, students’ STEM interests were leveling at best, per the FG#3 participants. Several other participants in FG#3 and FG#4 were unable to point to hard data to either prove or refute trends and had based their beliefs on personal observations of relative class sizes.

In general, the responses across the three focus groups were mixed, ranging from decreased engagement to a modest increase in engagement. The average of the responses seemed to indicate that interest had plateaued and no surge in interest was seen or that was anticipated in either direction in the near term. However, there was general agreement among the participants, especially in FG#3, that if the students were
“captured” at a sufficiently young age to participate in STEM programs (before entering high school), the greater the chance of their STEM interests transferring and persisting up to the time of high school graduation. Their observation pointed to a gap or inconsistency in the way STEM pedagogy had been implemented before and during the high school years.

Participants in FG#3 stated that the younger students in elementary and middle school had been exposed to an authentic and more progressive STEAM education whereas a more traditional STEM curriculum continued to persist at the high school level. The STEM students who had been exposed to a STEAM curriculum upon entering high school may have had an advantage in being better equipped to embrace and navigate the high school STEM programs. The further opinion of several of the FG#3 participants was that STEM and the humanities were disconnected and that the STEAM curriculum in high school was still very experimental and nonoptimal at best, lending to the problem.

Some of the STEM seniors in the honors program were naturally self-directed towards STEM and were college bound planning to major in a STEM field, according to participants in FG#3. They further stated that the serious-minded high school STEM students would often already be enrolled in college-level classes where they would present impressive research results and would participate in internship programs that led to industry connections and/or academic placements. In addition to cultivating STEM interest at a younger age, it was suggested that teachers can do more to help sustain the STEM pipeline during high school. Teachers should continuously nurture opportunities, build skills and confidence, instill a sense of empowerment and pride through
accomplishment, and create pathways that move the students in a direction toward STEM interests and career success.

Several of the participants in FG#3 also cited the need for a paradigm shift in STEM education, noting past attempts to redirect non-STEM students towards STEM only for them to become victims of STEM attrition over time. Part of the problem was rooted in the disconnection between STEM and the humanities. It was pointed out that English reading and literature influenced scientific writing style and where literacy was not confined to English but was also part of science lexicon (journaling, recording, and so on). STEM students generally saw English and the humanities as separate and irrelevant, and teachers have not effectively or sufficiently taught students about the subtle yet critical interdisciplinary connections. Indeed, the FG#3 participants agreed that English and the humanities were highly applicable to STEM or STEAM pedagogy and the various research areas that they represent.

Yet another detriment to increasing STEM engagement was the problem of an over-paced series of program trials that resulted in “STEM information overload” and “stop and go” rollouts, according to participants in FG#4 and FG#6. The rapid pursuit of one program after another, where each had been purported to offer the “next best thing” in STEM education and without fully evaluating the impact of one program before moving on to the next, placed a strain on the teachers, students, and curriculum delivery.

The “disjointedness” of programs over time had led to a confusing and bloated STEM education landscape, loss of focus, unachieved goals, and eventual teacher burnout and student disengagement contributing to the STEM gap—a tale of program stagnation. The teachers had been unable to effectively make interdisciplinary
connections because of state curricular constraints and had somewhat lost touch with teaching the lesson fundamentals. Students became disillusioned with what they perceived as a “jumbled” or clumsy program and with little choice but to drop out of the class or program.

According to participants in FG#4, a STEM Institute at ESM had once been proposed that would have provided for a consistent, focused, and streamlined STEM program designed to nurture students interested in augmenting their pre high school or 9th grade experience. The plan was to enable the students to decide on what to pursue in their interest areas and to allow them to change their minds as interests evolved. Complacency and apathy were the likely outcomes of delivering an inconsistent, unfocused, and inflexible STEM program that denies students a choice, per the participants. Students tended to retreat and focus on self-interests or pursuits they felt were beneficial to them without considering the larger picture.

According to the FG#4 participants, the students who disengaged from STEM may have convinced themselves that overachieving for college is unnecessary. They were less incentivized to hone their skills and be contented with just achieving a passing GPA (grade point average). A telling example was given of the many students who retreated to study hall for personal time and to socialize rather than attend STEM classes.

The next issue raised by participants in FG#4 centered on the theme of “no child left behind,” where students were taught to “trust the process” and were “trapped” doing what they had been told; that is, “regurgitating” the curriculum, being ultra-cautious so as not to experiment and take risks, and adhering to a culture of achievement defined by the state education standards built on a high-stakes Regents testing/grading system. A
progressive STEM learning approach called for students to take risks and experiment—something they were unaccustomed doing; and be creative and open to outside bodies of knowledge. However, that was unlikely to happen in view of today’s imposed educational curriculum, according to the FG#4 participants.

Compounding matters were “snowplow” parents who “cleared the way” for their children to achieve good grades and be eligible for college scholarships to reduce their financial burdens or obligations. Although the parents may mean well, this does little to prepare their children for college or the workforce. Participants in FG#4 and FG#6 offered joint perspectives on high school STEM students who were underprepared for the college STEM experience. They felt that such students would likely face a culture shock especially if they were unsure of STEM as a college/career choice yet decided to pursue it, or if they were underprepared and contented to strive for just a passing grade, or if they had altogether sidestepped the rigor of advanced STEM classes.

The scholastic demands of the first year of college and the lack of preparedness could shock or entice some STEM students into switching to a non-STEM major or dropping out altogether. A non-STEM major might offer a higher benefit-to-risk ratio in terms of a competitive salary and benefits, with less personal and financial investment and scholastic intensity, while avoiding the potential for stress and burnout. However, the source of the gap seemed to trace back to a bloated testing culture driven by state education standards coupled with school counselors who were uninformed and unable to offer effective guidance about the realities of the STEM landscape.

Communications through marketing was cited as another concern when the “urgency” of the outward messaging to constituencies is not grounded in fact or has
ulterior motives. According to several participants in FG#6, the federal government had
“hyped” the criticality of STEM education to the state education departments, school
districts, teachers, students, and industries at large. Funding and grants have been at the
heart of efforts to drive home the urgency of the message. The sense of urgency would
also seem to indicate that something must be done immediately to fill the nationwide
labor force gap with high-paying STEM jobs. The message is perplexing and suspicious.

The opinion of the FG#6 participants, however, was that the messaging had
lacked substance by not defining what STEM education truly meant and how to develop
and implement STEM programs for high impact. The messaging had been vague and left
open to interpretation, leading to a wide array of programs that on one hand, were
beneficial in terms of their diversity, but on the other hand, were confusing and
inconsistent with varied outcomes. The issue had also evolved into one of where or what
to invest in.

Although a spike in promoting the importance of STEM has occurred for over the
past decade, it will likely take the span of a generation to “get the message right” and
make STEM education truly purposeful to address the gap, according to participants in
FG#6. According to one FG#6 participant, although STEM had been a frontline topic for
years, more time is needed for its impact to “catch up” and meet today’s needs, or when
the STEM programs start to consistently produce stable, predictable, and desired
outcomes. “Whereas many good ideas have yet to be adopted for ‘mainstream’
implementation, it is important to allow time for the gap to close,” said the participant.

One FG#6 participant noted another barrier to STEM engagement—*inward*
messaging that fostered misconceptions about STEM and that could set students up for
failure as they enter college. According to the participant, the high school students, as a vulnerable population, were often unsure of their college/career path setting aside altogether their level of STEM affinity. When students who were uncertain had been strongly encouraged or pressured into STEM and when non-STEM pursuits were frowned upon, the outcome was that *having is not so pleasing a thing as wanting*. STEM may not have been a good fit for them after all and could likely lead to disengagement, thus adding to increasing attrition over time.

Deciding to pursue a STEM path yet barraged by messages like “STEM is hard” or “grades are key,” often sent the message to students that STEM is for the “elite.” This could lead to the formation of defeatist attitudes and outcomes that are counterproductive to the goals of STEM recruitment and engagement. A student’s recourse in this case might be to drop STEM in favor of a non-STEM major (for example, switching from a math to a business degree) considered less risky and just as equally rewarding. The conflicted messaging and resultant misconceptions about STEM as reserved for the elite, or that some majors were harder than others, helped explain the “flip of the switch” phenomenon culminating in STEM disengagement between high school graduation and the first year of college, according to participants in FG#6.

Participants in FG#6 further stated that STEM should not be advertised as an “uber-prestigious” aspiration that only those with the “right credentials” should pursue. STEM’s merit as an honorable college major or professional pursuit was not debated, but the STEM marketing strategies were in question. The FG#6 view was that STEM was simply not suited for everyone, youth should be exposed to STEM but not pressured into it, and students should be enabled to make their own choices. The viewpoint was thought
to help make the difference in achieving true and persistent STEM engagement. The next section extends these lines of reasoning, from an educator perspective, on long-lasting STEM engagement through effective interventions focused on content and delivery.

Interventions/remedies. It is well understood that the level of STEM engagement is directly proportional to one’s STEM affinity, the way STEM content is delivered, and a nurturing STEM learning environment among other aspects. STEM affinity aside, some environments and delivery mechanisms are more effective than others. Regarding STEM learning, the widely-held view is that an interactive, multidisciplinary, and practical or hands-on approach is far more engaging than a traditional, siloed learning approach—an anticipated conclusion. The present question asked is, “How could STEM learning be delivered in a more interesting or effective way for lasting effect?” The question explored ways to increase STEM engagement during high school that would reinforce persistence long after high school by examining concepts and tested strategies with a lasting impact.

The participants in FG#3 reiterated the importance of teachers and school counselors dispensing authentic, informed guidance to students about STEM opportunities; building on practical, real-world, and hands-on treatments rather than a dry, rote learning and “told what to do, per the curriculum;” and enabling students to autonomously make choices tempered by expert guidance. The participants, as teachers, felt that they were doing their jobs and fulfilling on the curriculum but were trying to make interdisciplinary connections and “stretch” the curriculum when the opportunity arose and time permitted. When possible, they used thematic framing to address a given
problem or issue by having the students develop a multiprong strategy with a diversity of perspectives to go beyond just a scientific experimental thought frame.

According to participants in FG#3, the ESM High School teachers had examined ways to help students overcome cultured siloed learning by showing them how interdisciplinary connections work and that no one subject is a disciplinary “island” unto itself. The belief was that once students were explicitly shown how and what connections exist, they were inspired to seek out connections for themselves. Via the thematic approach, topics in science coupled with nonfiction English Language Arts (ELA) books were used in situ providing a timesaving alternative to rote reading to engage the students and facilitate open, diverse conversations on relevant interdisciplinary topics.

The initiative to actively pair subjects and show disciplinary connections was a work in progress because of the need to resolve lesson block schedule conflicts among the teachers. The conflicts, along with other challenges, made it difficult for teachers from different disciplines such as science and English to pair up and jointly give classroom lessons on interdisciplinary connections. A participant in FG#3 offered the example of computational mathematics introduced into math lessons. Participants in FG#3 and FG#6 noted that finding ways for teachers from different disciplines to work together in this way remained a common goal. More work was needed to implement effective approaches that would include introducing as many practical, hands-on activities as possible and not creating “artificial” or forced connections or ones that did not naturally fit together.
The ability for educators to teach without the burdens of the standardized tests was again strongly advocated by participants in FG#4; standardized testing was viewed as a barrier to true pedagogy. Although teaching interdisciplinary connections such as in mathematics was a worthwhile endeavor, the reality was that if the students underperformed on the end-of-semester or year-end tests, it would not reflect well on the state teacher assessments. An undesirable outcome could force such programs to be abandoned in favor of satisfying the state education pass/fail criteria.

Indeed, the idea of passing the scripted state tests had been drilled and ingrained in students’ minds to the point of striking fear and causing burnout due to the “barrage” of testing they face. The opinion of the FG#4 participants was that the overemphasis on test scores as a key performance measure was “superficial” to real or deep learning, was not an accurate reflection of success, and was meaningless and counterproductive to the goals of learning. The FG#4 participants strongly expressed the consummation by the fear of passing the tests was not only psychologically stressful and unhealthy for students but could negatively affect their decision to pursue a STEM field in college.

According to participants in FG#4, the teachers were often torn between defending their professional beliefs and being obliged to adhere to the mandated policies and standards. The participants emphatically stated that such testing sent the wrong message to the students. The test scores were not a reliable measure of success and passing the tests erroneously implied that all lessons had been learned and the necessary knowledge had been acquired; realistically, the inverse proposition was considered more accurate and appropriate. The situation had forced the teachers to cover the required
content for students to pass the tests which in turn, limited the teachers’ ability to cover content beyond what the core curriculum allowed.

It was further stated by FG#4 participants that the ESM High School teachers were engaging, talented, and dedicated. They felt they had the wherewithal to effect positive change, but the lack of incentives and the rigidity of the “system” made effecting change a difficult prospect; the situation would continue to worsen for STEM engagement without state education board and school district buy-in of much-needed reforms. The belief was that change should not be on the teachers alone; it must involve the cooperation of the district and state education agencies. The participants across the three focus groups expressed concern over the need for more aggressive steps at implementing changes by the district and state education leaders.

Several of the FG#6 participants also felt that multidisciplinary STEM projects were a work in progress and that much more progress was needed before the projects had a broader scale impact at ESM High School. Success on that front was largely affected by the constraints of teaching in conformance to the NYSED curriculum and Regents testing standards compounded by the teachers’ limited time and resources in delivering expanded interdisciplinary content. It was stated that ESM High School had advertised an interdisciplinary STEAM program but realistically, it was limited and sporadic at best due to the state constraints.

From a macro view perspective, participants in FG#6 thought that a possible reason why other countries were academically outperforming the US in STEM subjects was the absence of such constraints. Nearly one-third of the student population in some nations has been exempted from pursuing higher education and encouraged instead to
pursue a trade career and where some females have little choice but to be homebound childcare givers, said several FG#6 participants. According to them, only the top-performing students advance to university education.

The foreign national pipeline model tended to “bin” people by professional, trade, or homebound career path to redirect talents where they are best suited and route national educational resources where they are most needed. The foreign national pipeline, contrasted with the U.S. educational pipeline, lacks policies in support of equal opportunity in education and careers. Despite the lower numbers and standings reported in STEM, the U.S. policy has demonstrated the value that America has placed on education. The participants felt that maintaining the status quo in STEM educational practices would only exacerbate the disparities in STEM outcomes.

Interventions, reforms, and policy changes were called out to mitigate barriers to STEM entry by students across socioeconomic and sociocultural boundaries. The point was reiterated on behalf of answering the fourth research question (RQ4) to be discussed later. The participants’ concerns were over denied opportunities for access to STEM career materials. According to one FG#6 participant, “systemic” issues and shortcomings in academics made accessibility difficult for those not of privilege, wealth, class, and power—an elitist thematic. Interventions that democratized accessibility to STEM would be part of a broader, longitudinal strategy to prioritize education and grow the STEM ecosystem regardless of socioeconomic status. The participants, in their role as teachers, felt that without taking more aggressive steps to address the systemic issues, denied accessibility will be harmful. Inaction will contribute to a greater societal concern—middle class erosion as a socioeconomic issue—in addition to widening the STEM gap.
Returning to multidisciplinary interactions, one of the FG#6 participants stressed the importance of intersecting the two domains of science/technology and art/design, which generally do not overlap and were often viewed as mutually exclusive. Each domain has its role in multidisciplinary STEAM education and a deep overlap was believed to exist. According to participants in FG#6, it was nearly impossible to find the *unicorns*—individuals with a unique and balanced mix of technical expertise and artistic skills—or those who are strongly overlapped in both domains. Such individuals can command high salaries in industry because they are often uniquely talented and difficult to find. The point made here was that multidisciplinary STEM education can provide a pathway to rewarding professional growth opportunities and other benefits across multiple dimensions (personal, societal, and so on).

One FG#6 participant stated that today’s STEM struggles will continue until the educational system hires people who are the pedagogical and technical/creative equivalent of a unicorn. Identified was the need for teachers to band together and freely design content modules and be entrusted to deliver an educational product that ultimately supersedes or altogether replaces the state testing standards. The thrust remains challenging due to the slow pace of adoption at the state level along with other bureaucratic and political barriers.

Ensuring that the classroom environment is interesting, thought-challenging, fun, and inviting was another theme raised on behalf of increasing STEM engagement. Participants in FG#6 expressed concern over teacher complacency coupled with boring content delivery in the classroom that could fuel disengagement. Similarly, mitigating student apathy or boredom was an important part of the STEM learning and engagement
strategy. Whereas these were obvious considerations, the point was that an overall strategy should build on teaching practices, methods, and styles that ensure an environment conducive to learning engagement.

The theme of increasing STEM engagement in this section focused on interventions highlighting curriculum reform, conducive pedagogical environments, effective outreach practices, engaging delivery mechanisms, and policies and strategies for expanding the STEM ecosystem. The theme is further extended to encompass the subject of mathematics in the next section. Of particular interest are (a) how teachers and students view disciplinary connections to mathematics; (b) what fears or apprehensions arise regarding mathematics that contribute to STEM disengagement; and (c) what techniques have been successful in overcoming fears of math as a STEM pillar. A point worth raising is that math permeates every aspect of our world—across virtually any subject, field of study, or domain of interest. The next section explores the various math and STEM engagement touchpoints.

*Math phobia.* Mathematics describes the way everything in the universe operates in accordance with the laws of physics and the general sciences. Mathematics is often called the language of the arts and the sciences. One perspective on math is that it is the “glue” that binds all the disciplines together. Another perspective is that the lack of mathematical insight and meaning lessens one’s ability to grasp concepts of the natural world and comprehend how to effect change. The speculation is that a fear of mathematics can contribute to STEM disengagement exposing yet another gap. The greater the understanding of how math permeates the physical world and how it weaves together various disciplines, the more one is apt to explore things at a deeper level.
However, the outcome is dependent on each person’s STEM affinity and skills to deal with mathematical concepts.

Some people will step up to the challenge of math and learn (fight) whereas others will disengage (flight). Therefore, the joint question asked of the educators is, “Do you encounter students that fear mathematics? If so, how would you help overcome the fear if it arises?” The joint question attempted to examine the link between the fear of mathematics and STEM engagement. It explored whether and how an apprehension of mathematics could contribute to STEM disengagement knowing that math is one of the STEM pillars and is tightly woven throughout all STEM and non-STEM subjects.

To begin, the participants in FG#3, FG#4, and FG#6 overwhelmingly acknowledged having dealt with situations of math anxiety or math phobia with their students. A less than student-friendly curriculum regarding how math was taught and applied had been conjectured. The students were often observed working on math problems in study hall and during their free time out of fear of failing the state Regents tests. Although some students had a strong affinity for math, others were apprehensive or plainly disliked the subject.

A synthesis of the data collected from the teacher focus groups offered some key insights. Their joint perspectives uncovered the following reasons why students had expressed anxieties over math: (a) a lack of self-confidence, (b) a discomfort with abstract mathematical concepts that seemed disconnected from reality, (c) a feeling of unbelonging or not fitting into a math class with others who excelled at math, (d) the broader demands of passing the state Regents tests, (e) a lack of self-efficacy in developing or possessing the requisite math knowledge or skills to pass the class, and (f)
a fear of failing. According to several participants across the three educator focus groups, some students felt “defeated” from the start and early on sought to drop a class that involved the application of math skills.

The teachers had willingly intervened to help students overcome negative attitudes about math and took steps to empower and engage them, dispel their worries, build self-confidence and self-belief, and encourage them to keep trying. The teachers routinely took the time to work with the students to dissect the root cause of their apprehension and helped them cope with fear often with the aid of a dedicated math teacher. They had worked to preempt defeatist attitudes from setting in and overwhelming the students. However, the high school teachers had found it difficult to sustain engagement in some cases, according to several participants across the educator focus groups.

Participants in FG#3 stated that the high school teachers had to deal with undoing a legacy of math anxiety seeded at the elementary/middle school level in which phobias were “projected” onto students, albeit with good intent, urging them to “get the math right.” The approach had unfortunately backfired according to the participants, because of a “cultural difference” in the high school teachers’ expectations of students’ abilities to apply the previously-learned math. Participants in FG#3 and FG#4 stated that the incoming high school students arrived with an intrinsic defeatist attitude regarding math and erected walls that limited their capacity to advance and succeed in STEM. An incoming anxiety over math naturally created a challenge for the high school STEM teachers who believed the students had the capacity to be successful, but where the students were less self-driven because of their fears.
The high school STEM teachers found effective ways of bridging the students’ knowledge gained in previous math lessons to real-world problems. The teachers felt bound by their belief in the students’ potential to succeed at math and worked hard to ensure their academic advancement. Several of the FG#3 participants suggested that professional development training would have been useful in facilitating a “cultural shift” at the elementary/middle school level, although the situation had been improving. Particularly, staff training in confidence building could have helped the teachers and younger students see math, failure, and persistence through a new and different lens.

Another challenge, according to participants in FG#6, had been the students’ dependence on tools to accomplish basic mathematical tasks. For example, students had come to depend on electronic calculators in the classroom, but their use had often been restricted to classes such as pre-college Calculus. Although the students had routinely relied on such tools, the teachers discouraged their use for basic math calculations that could be mentally performed. By limiting their use, a student’s comfort level and confidence level dropped leading to precipitous withdrawal and disengagement.

Next, to address the abstract nature of math, several participants in FG#4 were enthusiastic in recommending that steps be taken to show math’s relevance to real-world applications. Unfortunately, the teacher’s capacities for this were limited because of the need to prioritize efforts towards preparing students for the state Regents tests. It was agreed that more could have been done to relate the math to the domains of finance (budgeting, accounting, and investment) and a host of other practical applications that are part of a student’s life learning and skills development.
Regarding the lack of students’ self-confidence, self-efficacy, or self-belief in their math abilities, the participants in FG#6 offered several thoughtful insights. For instance, the students tended to express a sense of failure and then surrendered when they were unable to grasp a concept, or when the correct answer could not be found on their first try. The problem fundamentally reduced to their unwillingness or inability to embrace and deal with failure. The teachers were empathetic to the problem and frequently worked with the students to help them understand that failure is a good teacher. The teachers had stressed perseverance through trial and error and by trying over again as necessary, as part of an overall learning process. They taught that persevering to localize mistakes involved critical thinking and realizing the moment of knowledge discovery, and then reflecting on the process to reinforce what had been learned. The teachers offered themselves as role models stressing their foibles to students by showing that even they did not always get the correct answer the first time despite their training, skills, and experience to undertake the task.

Instant gratification was identified as another factor affecting one’s ability to embrace and manage failure in a STEM learning context. The participants in FG#6 conjectured that instant gratification derived from on-demand access to information through the Internet or smart phones. Many teachers at ESM High School stopped assigning homework because they had assumed the students would find it difficult, frustrating, and would give up if they were unable to immediately arrive at the correct answer, and that they could easily resort to finding the answers online. Some teachers had recognized the problem and posted the answer key to have the students grade
themselves. Except in certain cases, finding the answers online did little to teach the students good study habits.

Homework had become more of a “chore” for many students, in the eyes of educators. The added viewpoint was that students had been cultured and influenced by the state standards’ “take the test, grade every question” mindset. Consequently, the students were prone to studying or preparing for the tests, which in turn, played a hand in the teachers’ grading process that also accounted for students’ classroom participation and effort displayed in the classroom; if the teachers noticed that students were trying, they would be graded accordingly. The point here is that instant gratification combined with a culture of state testing standards, scripted programs, and institutionalized grading criteria conspired to widen the STEM gap.

The findings showed that the educator focus groups had covered significant territory on the STEM engagement and persistence front. The data analysis of the educator focus groups unveiled the following key themes: (a) evolutionary STEM pedagogy, (b) the impact of integrated and multidisciplinary learning, (c) engagement detractors and best practices, (d) applying learning modalities, (e) how non-STEM subjects (the fine arts such as music) fit into the STEM learning framework, (f) creative learning environments, and (g) a potential unified framework for integrated, multidisciplinary STEM and non-STEM engagement through mathematics. The analyses which follow will mainly focus on the relationship of disadvantaged or underserved groups and STEM engagement and persistence, including relevant social justice issues and related considerations. The next section will examine females’ perceptions of STEM as a college and career choice.
Female STEM engagement/persistence. The question asked here from the perspective of educators is, “How do you think females view STEM as a college major or career choice?” Important to note is that the present study did not aim to conduct in-depth research on female engagement in STEM; except to identify new, relevant findings undocumented in prior studies to the best of the researcher’s knowledge. The above focus group question builds on well-documented research on the dearth of females in STEM fields. Chapter 2 reviewed at a high level many of the factors contributing to the lack of female STEM engagement. The question was meant to identify other mitigating factors endemic to ESM High School that could enhance an understanding of the fundamental issue. Particularly, this segment of the educator focus group sessions was aimed at identifying reverse trends where engagement may have increased and the reasons behind it, as discussed next.

From the perspective of teachers, females’ interest in STEM as a college major or a career choice has grown over the last several years. Most of the participants in FG#3, FG#4, and FG#6 felt that the STEM fields were still highly male-dominated, although there was a steady shift towards gender parity, but it is still far from being balanced. A couple of the participants in FG#6 were uncertain of the current trends. The participants generally agreed that females had fallen victim to the STEM stereotype that has thoroughly ingrained our society, and which has been outrageously perceived by some as “diminishing” the feminine. The stigma has persisted and traces back to well before the era of the 1960s.

The traditional view has been that females were not well suited to engineering or technical fields and that frame of thought has influenced the human psyche and societal
norms and expectations for decades. A feminine professional pathway has largely been disassociated from STEM fields and viewed as an exception rather than the rule. Several participants in FG#6 expressed disheartenment at the dearth females entering STEM fields following high school even till recently. Historically, gender bias could be traced back to social and religious misogynistic beliefs of early civilizations that persists to this day, said one of the FG#6 participants.

The shifts towards female STEM engagement had occurred at different rates depending on the subfield of STEM considered (for example, chemistry, physics, biology, life science, healthcare, medical technology, and so forth). Nonetheless, the aggregate of subfields under STEM had shown a net increase in female engagement over at least the last 5 years according to participants in FG#3 and FG#4. One of the FG#4 participants did not understand why there should be any gender disparity in STEM but agreed that such disparities were rampant.

Anecdotally, another FG#3 participant cited a female generational skip in STEM interest that seemed to have alternated since the Baby Boomer generation (1946-1964). The increased rate of engagement with the Millennial/Gen Next and Gen Z (1980-2012) generations may somewhat track with surges in technological advancements characteristic of the 4th Industrial Revolution period. Also noted was that academic institutions seemed to have made concerted efforts more than ever to recruit, retain, and support females in STEM fields.

Whereas one of the FG#3 participants claimed a substantial increase in ESM High School females applying for college STEM majors compared to 5 years ago, another FG#4 participant had the opposite opinion citing the struggle to engage females in STEM
and stating that they simply do not gravitate towards STEM. Other participants across the three focus groups had expressed mixed opinions and outcomes on the matter. As teachers though, they actively reached out to (female) students to help dispel gender-bias stereotyping while curating opportunities and cultivating self-efficacy regarding their STEM pursuits.

The teachers also articulated explicit associations between strength and empowerment and being a woman in STEM with their female students. The importance of exposing females to STEM at a young age was further emphasized. Such exposure establishes a foundation for growth in engagement in the higher grades, according to participants in FG#3. Although the situation had been slowing improving, an FG#4 participant felt that teachers, female students, and society at large were still walking a “fine line” between realizing females’ potential in STEM fields and the overshadowing stereotype beliefs. All the participants across the three focus groups concurred that more work was needed to engage females in STEM by breaking down the gender-bias stereotypes.

Participants in FG#3 further stated that Information Technology (IT) companies like Google and Facebook were aggressively recruiting candidates to fill jobs and match diversity goals focusing on females with propensities towards STEM and engineering design; albeit the schools have not produced a wealth of candidates currently in the STEM pipeline. The point on corporate recruitment elicited a contrarian response and raised a new question: *Is the STEM community perpetuating a myth by forcing an agenda and propagandizing and promulgating a misconception?* A couple of the participants in
FG#4 thought that the STEM community had effectively “brainwashed” females into believing they should be part of what has admittedly been a male-dominated club.

The participants further stated that the STEM movement had (allegedly) created a falsehood by convincing society of an artificial need to push females into STEM; additionally, the STEM agenda tended to challenge females’ freedoms by pressuring them into STEM while discouraging them from naturally choosing fields or professions that they felt more inclined to pursue. Forcing an unnatural change using false claims of an unfair gender imbalance was counterproductive and exploitive when realistically, it is the way it is, said the participants. They believed that STEM gender imbalances occurred naturally and that brain-based physiological differences existed between males and females in the way each handled problem-solving tasks. In their opinion, males’ and females’ brains were simply structured (“wired”) differently and each approached problems and solutions in a much different way, which explained why females did not gravitate to STEM. Consequently, the STEM community’s expectations may be too impractical and unrealistic when it comes to female engagement, influencing wishful thinking. Their view was that the STEM gender imbalance existed naturally. The viewpoint led to additional discussions as follows.

The same participants in FG#4 stated that, posed with the same technical problem, males were observed to immediately jump in and troubleshoot to arrive at a solution. On the other hand, females tended to give pause and be more analytical (first examine and then analytically determine) in arriving at a reliable, workable solution. One FG#4 participant claimed to have seen the same outcome many times over the past 20 years. To drive home the participant’s point of gender-specific behaviors and responses to a
given situation, the example of changing a flat tire was used: males will immediately change the tire whereas females will review a checklist of steps first and then change the tire in a way that makes the best sense. One of the female participants in FG#4 agreed with the example. Other participants in FG#4 questioned the basis of the controversial hypothesis and countered it by stating that how one approaches a problem-solving task is not gender-specific but more problem- and person-dependent. Each person, not necessarily gender, differs in the way he/she approaches a situation.

Notwithstanding, the FG#4 participants were adamant in their belief that gender-bias stereotypes were significant barriers to overall STEM engagement and persistence. Regarding STEM fields or for that matter any profession, the emphasis should be on an individual’s passion, talent, fit, and choice. It should be about moving past the stereotypes and not being driven to fill an “artificial” quota, said one FG#4 participant. Indeed, two of the FG#4 participants, although highly in favor of recruiting females in STEM fields, expressed a strong displeasure for the constant push in that direction. As one of the participants said, “Create the opportunity but do not force them. Let them guide you if the passion is there, not guide them if it is not.”

It was further suggested, as a synthesis of points raised by the participants across all three focus groups, that the teachers should be factual and honest with their (female) students, create the opportunity, raise awareness, guide understanding, avoid differentiating based on gender, and certainly not force the issue. Another participant from FG#6 stated that their job as teachers was to expose females (and all students generally) to as much content as possible and to let them decide what interests them and what they want to pursue. The participant further stated that it was a disservice to
females when foisting the STEM career agenda on them especially if they were STEM-disinclined, adding to the disengagement and attrition. The teachers often expressed their elation at hearing about a female’s voluntary decision to pursue a STEM field.

Several of the participants in FG#6 firmly believed that one of the main issues in female STEM engagement was the tact (voice, messaging, and attitude) that had been used by teachers, alluding to female empowerment in choosing what they want to do, become, or pursue. Instead of questioning or challenging their choices, a more effective tact would have been to nurture, guide, and expose them to opportunities and options to help them make informed decisions in pursuing STEM or any other field of interest.

According to several FG#6 participants, balancing the importance of salary against personal sacrifice, time investment, and honing one’s talents and abilities in a professional development sense is key to making informed decisions regardless of gender. Hearing female success stories in STEM can be influential in the decision-making process as are stories of failures including the influence of peers. It was incumbent on the teachers to employ the right tact to help females make sense of their choices and make informed decisions, said the FG#6 participants. One participant in FG#6 deemed it socially unjust to question females about their choices when it came to STEM. Questioning whether they were “sure they can do this” and messaging that “it is not too late to switch majors” translates into “maybe I cannot do this” and leads to self-doubt, self-defeat, and resignation.

Another participant in FG#6 was concerned with the message “STEM for girls” because of its apparent polarizing effect on attitudes towards STEM engagement. The participant felt that this had been part of the problem, although other participants
understood this as advocating for female involvement in STEM since males were already heavily engaged. Advertising a subliminal theme can give rise to polarizing views and attitudes on the theme and its underlying message. It was the FG#6 participant’s opinion that if the marketing were not to implicate gender in the message to begin with, then the myth and misperceptions would not surface. It was recommended that the STEM community and its leaders rethink their recruitment strategy and retention goals. Unfortunately, when referring to STEM or a subset domain like coding, the reflexive response is to think a “male activity.”

Next, several of the FG#4 participants expressed concern over federal legislation that incentivized large technology companies to hire based on meeting quotas across, gender, race/ethnicity, and other socioeconomic and sociocultural criteria. The intent here was to encourage diversity, inclusion, equity, equal opportunity, and social mobility in the STEM workforce through affirmative action law. However, the plan has backfired by the onboarding of unqualified candidates who were hired to meet criterion-based quotas. This has resulted in workforce and workplace tensions. Hiring should be based on talent and capability (or, who is the best fit for the job).

Workforce tensions referred to an imbalance in workforce supply and demand of certain types of skilled labor that could be difficult to find matched to positions that could be difficult to fill. If unqualified individuals were hired to meet criterion-based quotas, and if those individuals were unsuited to the position, then this can add to the attrition count thus exacerbating the STEM gap. One participant saw this as a next step in an ill-advised policy that sets itself up for failure because it neglects the science and the labor
force data (regional demographics, hiring trends, talent pools, matched skill sets, socioeconomic factors, human behaviors, personal preferences, and so on).

An additional point worth noting was an anecdotal account made by an FG#4 participant of businesses that hired people of only one gender type. The decision was based on certain cultural, image, and personal values or preferences. Admittedly, the hiring practice could have been legally challenged as an alleged violation of equal opportunity law. The discussion then pivoted to how disadvantaged and underserved groups could be better served in STEM fields and the relevant factors that contributed to engagement gaps. The topic is discussed next.

Disadvantaged/underserved STEM engagement. The question asked here of the educators is, “How could we better engage women, disadvantaged, or underserved groups in STEM?” The question extended the prior focus group discussions on female engagement in STEM by generally considering disadvantaged and underserved groups at large. The only additional perspectives offered here were that many of the issues identified for women also applied to STEM outreach and capture efforts for virtually any disadvantaged or underserved groups. The belief was that progress was being made on these fronts because communities of interest were aware of the many relevant issues facing such groups, but more work needed to be done, can be done, and should be done.

The FG#3 participants identified another perspective though. In addition to the gender-bias gap, they cited socioeconomic factors that needed to be more closely examined. The relevant socioeconomic issues and contributing factors were tied to federal and state legislation. The opinion was that socioeconomics outweigh the gender-bias issues in terms of a greater number of class and race issue that such groups have
faced. No solutions above and beyond those identified for the female groups were identified or articulated.

The section which follows articulates the findings from the data analysis that were used to answer the fourth research question, RQ4. The question probed into strategies or interventions that could be used to increase STEM engagement and persistence to narrow the STEM gap from both a student and an educator perspective. The perspectives and data findings are presented in the next section.

**Strategies or interventions to increase STEM engagement and persistence to narrow the STEM gap: students’ and educators’ perspectives.** RQ4 which asked, *From the perspective of students and educators, how can interest in pursuing a STEM major in college or a STEM career be increased?* probed into ways of increasing STEM engagement and persistence to narrow the STEM gap. The findings for RQ4 helped to construct micro views of the student and educator perspectives as the next to last step in arriving at a macro view understanding of the STEM gap problem using the methodology of Figure 4.1. The results of the data analysis for the student- and educator-based focus groups are provided in Appendix F, Table F1 and Appendix G, Table G1, respectively, and are discussed in detail in the next section. The results for the student focus groups are presented first as follows.

**Student focus group findings.** The sections that follow will individually address the findings for the remaining three a priori dimensions: (a) STEM influencers versus non-STEM careers, (b) social justice, and (c) STEM thought leadership. These dimensions correspond to the last three student focus group questions (FQ13-FQ15) used to answer RQ4 and that were itemized in Appendix F, Table F1. The next section
addresses STEM influencers versus non-STEM careers from the perspective of the student. The section expands on the theme of incentives that drive individuals to either pursue a STEM or non-STEM career such as salary, status, or other factors as follows.

*STEM influencers vs. non-STEM careers.* The widely held belief is that STEM can open doors to a broad range of rewarding academic and career opportunities. An obvious benefit is the chance for landing a high-paying job and to contribute to innovation and technical advancements. Notwithstanding salary, lofty aspirations, or other compensatory benefits, the opportunities for trade and vocational jobs including certain non-STEM fields can also offer competitive salaries and other benefits. The STEM fields have often been associated with the notions of rigor and sacrifice, and the personal and financial investments that accompany such pursuits. Realistically and fairly, any field of work or study will have its own set of demands, commitments, and rigors. Therefore, any academic major or career pursuit should be thought of in broader terms to arrive at a decision that matches one’s personal interests considering other life factors. The question asked here is, “Why would you consider pursuing either STEM or non-STEM as a career choice (salary, advancement, challenge, opportunity, other)?” The question challenged the participants to think along broader dimensions of what might drive them to pursue either a STEM or a non-STEM career path as discussed next.

Regarding the pursuit of either a STEM or non-STEM career, a series of key themes emerged as follows. First, although some participants in FG#1 viewed salary or compensation and personal interests as important in one’s decision to pursue one or the other career path, several participants in FG#2 and FG#5 found other variables more vital; collectively, the variables outweighed salary as a deciding factor. Synthesizing the
ideas across the three focus groups, the other variables identified included: aspirational (enjoyment, challenge, occupational diversity, sense of fulfillment or reward, opportunity for making a difference to society, and professional advancement); market demand or job availability; the amount of “investment” willing to be made; and a host of other tangible and nontangible factors. Participants in FG#2 stated that females were often compelled to make a statement about the growing number of women entering the STEM fields and that there were no limits in response to disparity issues. The participants across the three student focus groups unanimously agreed that any career decisions should not be based solely on personal interests or desires but should balance multiple factors (job demand, advancement opportunities, salary, and so on).

The focus group discussions then shifted to STEM and social justice issues. As a logical next step, the following section will bring together several of the issues previously addressed for disadvantaged and underserved groups including females, and the factors that influenced STEM career decisions within a social justice context. The point of departure for the next question was on how STEM could help achieve the goals of social justice pertaining to leadership on the equity, equal opportunity, and social mobility fronts. The conjecture was that the pursuit of a STEM field can lead to a well-paying career and lend to a sustainable, competitive STEM workforce. The next section further elaborates on these points.

Social justice. STEM is indeed part of the social justice landscape. Historically, STEM positions have been among some of the highest paying jobs in the US. Generally, the barriers to the STEM fields have existed as evidenced by (a) the increasing number of unfilled STEM jobs, (b) the less than desirable academic ranking of U.S. students in
STEM compared to other countries translating to a less competitive, global technological workforce, and (c) the STEM pipeline leakage that occurs between the time of high school graduation through about the first year of college. Further, barriers to STEM opportunities exist for disadvantaged, underserved, and underrepresented social groups for a variety of reasons. The question asked here is, “How could STEM help to address or solve social justice issues and which issues are of concern?” The question further probed into how STEM could ameliorate the social inequalities (for example, declining equity and equal opportunity for well-paying jobs and social immobility). Many of the points previously raised under FQ11, FQ12, and FQ13 for the student focus groups are directly applicable to the above question.

Synthesizing the responses across the three focus groups, the recurrent themes in this part of the study were gender parity, equity, equal opportunity for high-paying jobs, reward or fulfillment, financial security, social mobility, and personal happiness. Other social justice considerations included: technology’s role in society for improved quality of life per participants in FG#2 and FG#5; opportunities and incentives for underserved groups per FG#2 participants; philanthropic and humanitarian causes per FG#5 participants; contributions to job growth and societal financial health per FG#5 participants; and corporate or other organizational outreach that leads to myriad opportunities per FG#2 and FG#5 participants. A participant in FG#2 offered a dual argument on the value of (STEM) education: a metaphor was offered on the dropout who becomes a successful entrepreneur without the benefit of a formal education which conflicts with messages on the importance of higher education, giving the populist
impression that higher education is indeed an *elitist* ambition—one of the possible underlying causes of STEM attrition.

The participants felt that their ESM High School STEM experience helped to inform their opinions on the value of STEM education and engagement and on the underlying social justice issues and leadership strategies. The discussions then segued into an open-ended question and answer segment in which the participants in each of the student focus groups were given an opportunity to provide additional insights. The concluding student feedback is given in the following section.

*STEM thought leadership.* At the close of the student focus group portion of the study, the participants in each group were given an opportunity to offer additional insights and feedback. The participants were asked, “Are there any other thoughts or ideas on STEM engagement strategies you would like to share?” The question was intended to elicit other thoughts, concepts, or ideas that may not have been previously covered or that warranted further discussion as pertaining to STEM engagement and persistence. The additional insights and perspectives are provided as follows.

Participants in FG#1 and FG#5 reiterated the need for expanded outreach and advertising of the STEM program to elementary and middle school grades. Participants in both FG#1 and FG#2 recommended that the new outreach should include marketing, presentations, and visits to describe traditional STEM/STEAM and specialized programs (aeronautics, automotive, construction, and others). To further raise awareness, the students should actively promote the STEM program by talking about their experiences and knowledge gained, friendships formed, and the many fun group activities and learning opportunities. Participants in FG#2 reiterated the importance of having local
technology companies step up active outreach and engagement to offer internships, engineering scholarships, and financial aid/incentives for disadvantaged or underserved STEM-oriented students. Assuring continuity in teacher/counselor/mentor support systems stood out as a major gap concern in the strategy to ensure informed guidance.

High-level strategies were discussed for boosting the U.S.’ ranking as a global STEM leader starting at a local or grassroots level. A counterpoint was raised begging the question, “Why should anyone care which countries are the STEM leaders if humanity worldwide was benefitting regardless of the source of STEM advancements and innovations?” The counterpoint raised concerns that amplify the importance of the research problem pointing to STEM as a national priority for the reasons discussed in Chapters 1 and 2. Notwithstanding, additional recommendations were proposed that represent a synthesis of ideas and opinions across the student focus groups as follows:

- Increase the number of community STEM events to raise public awareness first-hand of STEM program impacts and benefits;
- Improve the marketing and advertising of STEM courses offered;
- Build internal school engagement and promote a sense of pride;
- Assign STEM students real-world problems to solve each semester or at the end of a term to showcase and socialize the merit of the STEM program;
- Reinforce resident teacher/counselor/mentor support systems including female STEM support groups to motivate students and curb disengagement;
- Implement effective strategies to integrate the arts into STEM to stimulate reciprocal interests (for example, art/design concepts or ideas can intersect or
reinforce STEM interests, and STEM concepts and methods can feed into creative fine arts and design elements);

- Introduce younger students to STEM and build on their interests showing them the limitless possibilities;
- Avoid forcing the STEM agenda on students and discouraging or limiting their personal interests (enable and encourage choice via informed guidance);
- Better prepare students for the demands, rigors, and commitments in pursuing a STEM field to mitigate attrition during the first year of college;
- Promote the concept of well roundedness, balance, and the freedom to follow one’s passions or interests; and
- Strive for a diverse, social, and “fun” STEM agenda.

The above recommendations comprised the major feedback from the student participants in response to the focus group question to answer RQ4. According to the participants, the ESM High School leadership, administration, and STEM teachers were generally aware of the need to make certain improvements or adjustments in current policies, procedures, and best practices that would help improve STEM engagement upon graduation. Leadership or organizational change to enhance STEM engagement and local/regional impact was contingent on the close coordination with school district leaders and superintendents and with the approval of state education leaders. The next section analyzes the data gathered from the educator focus groups and presents the findings that were used to answer RQ4.

**Educator focus group findings.** The sections that follow will individually address the findings for the remaining four a priori dimensions: (a) in-class versus outside class
learning, (b) small-group collaboration benefits, (c) social justice, and (d) STEM thought leadership. These dimensions correspond to the last four educator-based focus group questions (FQ13–FQ16) used to answer RQ4 and that are itemized in Appendix G, Table G1. The next section addresses the first dimension, in-class versus outside class learning including cocurricular STEM activities and the relevant issues on STEM engagement, drawing on the educators’ personal experiences and perspectives.

In-class versus outside class learning. STEM learning activities outside the classroom offer certain advantages. For one, it exposes students and teachers to opportunities for exploring and observing important connections between the individual STEM subjects and thus, enhances awareness in multidisciplinary synergies. The question asked here is, “How do you view inside- versus outside-class STEM learning?” The question examined, from the teachers’ perspective, whether any differences, advantages, or drawbacks existed with outside or cocurricular learning versus learning in a more traditional classroom setting. The intent of the question was to identify additional component strategies that could contribute to STEM engagement and persistence.

One of the FG#3 participants talked about having been involved for over 20 years in an outdoor adventure club on environmental education that was STEM-driven by design and science content laden. The club had been conducted less formally than a classroom as expected and therefore, was less structured, less hierarchical, and non-imposing. Further, the students and teachers were better able to connect, interact, and communicate with each other, thus building relationships that effectively translated to the classroom. The students had been encouraged to explore and ask questions and express their interests in a nonintimidating setting. The participant felt that the study of nature
and water quality with lab exercises in a real-world context not only highlighted an important environmental theme but provided for an impactful learning environment. The key outcomes of the experience included success in building relationships and expanding awareness of multidisciplinary connections in a natural context that ultimately benefitted the classroom environment.

Based on the experience, grants had been submitted to build an outdoor natural learning lab at ESM High School and to schedule field trips to expand opportunities for students. The feedback from the students had been highly positive; they enjoyed this type of learning and the freedom to explore. An FG#3 participant added that it would have been advantageous to have experienced similar opportunities when (she) was growing up and that such an experience can influence career decisions. The FG#3 participants stressed the importance of an environment for autonomy or the freedom to learn coupled with internships that builds confidence through natural and practical learning contexts.

Facilitating opportunities for learning outside of the traditional classroom along with arranging internships at technology-based businesses allowed for up front and close exposure to the various facets of STEM “in action, in the field.” The participants felt that the opportunities for STEM learning in real-world settings were improving but were still limited. The teachers had been charged with exposing the students to learning opportunities outside of the classroom, inspiring them through real-world experiences (observing and interacting with natural environments), and enabling ways to help them interact with each other. One participant likened this mode of learning to witnessing a symphony and being inspired to become an orchestral musician.
The FG#4 participants felt that outside cocurricular STEM activities were just a “different kind of classroom.” Even the apparatuses used in any instructional class (science labs and school equipment, automotive lab and machinery, cosmetology chair, and others) were simply other types of learning “devices” albeit, unique and different from the traditional classroom environment replete with textbooks and lectures. According to participants in FG#4, the students were eager to experience lessons outside the traditional classroom setting if even for just a refreshing change of venue.

A complementary perspective, enthusiastically endorsed by several participants in FG#4 was expressed as, “Learn the basics in the classroom, then experience and put into practice the basics outside the classroom.” The viewpoint was akin to learning theory in the classroom and experiencing or applying it practically outside the classroom. Another viewpoint recognized the need to unleash the students’ fundamental thirst for knowledge and applying it, or the notion of balancing theory and research against practical experience and applied theory. Several of the FG#4 participants strongly felt that the most effective learning experience was the one outside the classroom stating that by far, their students clearly preferred and benefitted most from the outside learning activities.

One of the participants in FG#6 answered the question differently, in the context of student groups and outside group activities. The participant expressed skepticism of student working groups because of the fear that the collaborative process could be unproductive, underperforming, and could negatively impact students’ grades. From an in-classroom perspective, what was found to work was a type of project/goal-based learning model using a facilitator tier to assist the students across multiple projects and giving the students “ownership” of their individual projects.
The above process involved defining goals, providing guidance when needed, and empowering the students with the freedom to make their own decisions and execute the project steps as they saw fit to achieve their goals. The key was for students to take ownership of their projects and to ask questions, and for facilitators to monitor their progress and guide them. The facilitator or group leader then briefed the head classroom instructor on the project results. Indeed, the students resonated well with this approach. The modified group approach was much different from the traditional classroom style of teaching and more in line with outside or cocurricular STEM learning environments.

Another participant in FG#6 thought the above approach was less about ownership and more about the students being engaged and invested in their project outcomes. Allowing for that perspective, a positive outcome was anticipated as to how the group interactions and discussions unfolded, and where successful group dynamics depended on the group makeup and the nature of the project. Some group sessions were seen to work unbelievably well, whereas others were less than desirable. If the students were open-minded and engaged in a meaningful, purposeful in-class or outside-class project, they were more willing to invest in the process with anticipated successful outcomes.

Two of the FG#6 participants commented that the success of the STEM project-goal-based approach for in-class versus outside class environments depended on student “buy-in” or how they had planned for successful outcomes. It was suggested that the students be challenged to figure things out on their own and to witness the outcome of applying their problem-solving skills, to expect some outcomes to be better and others, and to manage failure. It was also suggested that the teachers and facilitators provide
some guidance but not too much “hand holding” in the process; assuming the students were serious and invested, they would try hard to achieve positive results because they did not want to fail.

The above strategy takes the students out of their comfort zone, engages them while instilling a level of confidence that they can achieve results regardless of the outcome, and keeps them focused by eliminating unnecessary distractions. In that case, “fires” do not have to be put out, chaos and confusion are mitigated, and the process becomes more stable and conducive to learning. Nonintuitively, placing them in a less structured environment outside the classroom facilitates this type of learning. The discussion later revisited the matter of group collaboration and group size as part of the in-class or outside-class STEM learning strategies. The issue is further discussed next.

*Small-group collaboration benefits.* The Chapter 2 literature research pointed to the benefits of small group collaboration in STEM projects such as technology and engineering project-based learning. Previous questions from the teachers’ perspectives that were related to integrated STEM learning (FQ4) and STEM learning modalities (FQ7) found small group learning problematic. The FQ14 joint question which asked, “In your experience, is small group collaboration beneficial? How and why?” revisited the issue of small group learning to further explore and substantiate the points raised earlier. It is noted that group collaboration and group size were not focus areas of the present study and were examined as collateral issues to identify specific experiences and observations that may either support or refute the findings of prior studies on the theme.

Participants in FG#3 reiterated the need to give the high school STEM students some individual discretionary time before engaging in any group collaboration. Once
they had the time to formulate their position and ideas, group or partner sharing could occur and a “growth” experience through dialogue can unfold. The approach (a) creates a “safe space” for individualistic concept development and preparing for the group activity, (b) enables a process for (small) group interactions and the vetting of individual ideas, (c) protects individualism while allowing others an opportunity to identify with an idea, (d) offers students “membership” in a classroom group culture to hasten personal growth, and (e) teaches students team dynamics as a career building tool. Another participant in FG#3 stressed the benefit of vetting ideas with individuals of diverse viewpoints and observing how ideas morphed within a group using the Covey’s $1 + 1 = 3$ rule (Covey, 2006); learning collaborative and democratic processes; and converting the “individual” mindset into a “group dynamic” mindset. The importance of (small) group culture, teamwork, and communication in eliciting responses from the students was stressed.

One participant each in FG#4 and FG#6 independently cited the benefits of one-on-one time between students in small groups that allowed for mutual relatability and communications and facilitated a forum for exchanging ideas among group members. Participants in FG#6 felt that the efficacy of small groups depended on various factors, such as the students’ grade and maturity levels. One participant’s experience with ninth-grade students was that they could not easily deal with small group settings. References were made to prior opinions and comments on small groups being problematic because of social, communication, and thought diversity framing issues; attempting to get students to do something in a small group was found to be challenging. Generally, it was more difficult to get students to think, decide, and act on their own without teacher intervention.
and telling them what to do. Notwithstanding, a small group collaborative was considered beneficial because of the chance for one-to-one interactions and relationship building, but potentially disadvantageous because of the lack of diversity and the smaller chance of cross-fertilizing concepts or ideas.

Another FG#4 participant focused on the drawbacks of small group collaboration. According to the participant, the reality was that small group collaboration at ESM High School had often been dysfunctional and where students demonstrated a lack of self-initiative. They may have naturally felt awkward or out of place being with others they did not know or typically did not communicate with and were being drawn outside their comfort zone. However, the goal of the group collaboration was to take the students beyond their comfort level, although a successful group activity depended on the students’ soft skills to undertake the endeavor. It was counterproductive for them to stay in their comfort zone and form small groups with others they knew or had befriended.

Another symptom of the problem is that usually only one person (typically the group leader) assumed the main responsibility for getting most if not all the work done. Small groups had been effective when the students were taught how to interact, be open-minded, and risk discourse. Industries in their recruiting desperately seek candidates with these skill sets. Unfortunately, many students did not comprehend or think they needed the social skills considered important for effective communication and group interaction, which are characteristic of industry integrated product team environments, stated one FG#4 participant.

Requiring that the students interact in small groups can be a foreign concept to them; some can adapt whereas others simply cannot, stated participants of FG#4. On the
other hand, some students were naturally inclined to be independent thinkers and were more productive working on their own; however, they should be taught to embrace diverse teamwork settings to develop their listening and communication skills without forcing compliance. In other words, if someone thrived and produced their best results independently, then it is senseless to deny them the opportunity and force them to follow a path that will not lead to a desired or productive outcome; yet they should remain open to the idea of group sharing. The issue remains a fine line for future dialogue and debate.

Another aspect of small group collaboration raised by participants in FG#4 was the concept of group “mix.” Small group dynamics and collaborative outcomes were not only influenced by the type of people in the group, the size of the group, and the subject or project under consideration; the group mix or makeup also played a crucial role. The idea of mix is found in the workplace and corporate boards and ideally is anti-homophilic based. This refers to selecting individuals for the group (founders, stakeholders, political representatives, technical staff, administrative support, subject matter experts, outside experts, and so on) and diversity criteria (like-minded individuals, contrarians, other), what they bring to the group (experience, relevance), and how to form the mix (an achievable balance of key individual traits and criteria). The mix can work on some levels and not on others and is not always an easy and straightforward process. The goal is to assure an effective group makeup, functionality, and ability to contribute to achieving productive outcomes on a case-by-case basis.

The conversations in FG#4 then turned to the subject of state testing standards and Regents exams pointing to another group collaboration issue—that of small classroom review groups aimed at addressing gaps in meeting the state testing standards.
One of the participants recounted an anecdote of a student who was motivated to pursue advanced mathematics and took review classes in preparation for the Regents exam. The student was “forced” into a situation where the classmates did not want to be in the class and/or were simply unmotivated and unwilling to actively participate in the review activities.

The student in this case was convinced that he/she would be solely responsible for completing the class project work. He/she felt obliged to be in a small group setting and was “penalized” by having to tolerate a nonmotivating environment and unwittingly became a “pushover” for others in the group. The collaborative process came down to discussions, determining what work needed to be done, who would do it and who would lead it, and the deliverables (presentations, posters, and so on). There were various points in the process where things began to break down. In the end, the group experience ended on an unproductive note. The story raised two issues according to participants in FG#4: (a) forcing well-intended students into an uncomfortable small group situation with diminishing returns, and (b) forming small review groups for the purpose of passing the scripted state tests. The latter again supported many of the teachers’ prior arguments for eliminating the Regents exams altogether.

In the case of students who were more independent, the FG#6 participants felt that individualistic work was a must but that they should also be taught to willingly expose themselves to the small group collaborative process. The approach was especially important when it came to the subject of mathematics because students with a sense of independence and self-assertion tended to “freeze” when discussing math topics in a
group setting; although, the behavior was grade/maturity-level dependent and the seniors were able to handle the situation better than the younger students.

The focus group discussions then shifted to STEM and social justice issues. The main point of departure was on how STEM could help achieve the social justice goals of equity, equal opportunity, and social mobility fronts. The conjecture was that the pursuit of a STEM field can lead to a well-paying career, create new opportunities, and lend to a sustainable, competitive STEM workforce. The following section further discusses these points.

*Social justice.* STEM is part of the social justice landscape. Historically, STEM jobs have been among some of the highest paying jobs in the US and offer opportunities for social mobility and other benefits. However, barriers to STEM field entry exist as evidenced by the following: (a) the number of unfilled STEM jobs, (b) the mediocre international ranking of U.S. students in science and mathematics compared to other countries—eroding technological workforce competitiveness in global markets, and (c) STEM pipeline leakage—the attrition that occurs between the time of high school graduation through the first year of college.

The barriers to STEM entry also affect disadvantaged, underserved, and underrepresented social groups for a variety of socioeconomic and sociocultural reasons. The question asked here from the perspective of educators is, “How could STEM help to address or solve social justice issues and which issues are of concern?” The question further probed how STEM could ameliorate the social inequalities suffered by certain groups regarding access to well-paying jobs and to identify other relevant issues. Several points previously raised under FQ11 and FQ12 for the educators were reiterated here.
Two participants in FG#3 spoke on the widening gap when it comes to serving the needs of underrepresented and disadvantaged students in leveraging STEM opportunities and acquiring competitive skill sets against a plethora of social equality barriers. Some STEM fields were more competitive than others and combined with socioeconomic or sociocultural factors, created barriers to entry in certain cases. On the other hand, STEM had enabled pathways for competitive skills development in some fields that engendered social justice and social equality touchpoints. The fields have included civil engineering, environmental engineering, wastewater treatment, and a variety of humanitarian and environmentally conscious professions in healthcare, medical technology, clean water delivery, and nutrition access services for inner cities. Such STEM-related fields have seen growth in recent years from virtually all segments of society. Concerns remain however, over the future of the broader STEM landscape.

Another FG#3 participant highlighted the need for teachers, mentors, and school counselors to establish an “ecosystem” for enabling access to STEM opportunities and raise awareness of the possibilities for social mobility or advancement. A “snowballing” strategy could be used to realize the possibilities as follows. Dialogue would first be initiated that unlocks new possibilities, thereby creating more opportunities, and facilitating access to a connected STEM-social framework encompassing multiple disciplines. STEM and a support system for curating the desired skill sets would be at the heart of an expanding ecosystem of opportunities to serve affected social groups in this way.

One of the FG#4 participants felt that the debate over social inequality in STEM reduced to a one-sided issue explicitly skewed towards females and where males were
implicitly overlooked in the argument. This raised another social injustice issue. The participant referred to missing strategies for explicitly encouraging males to enter nontraditional fields that were dominated by females beyond just STEM. The participant made the point of *democratizing* STEM for everyone, to maintain a fair and level playing field, and to not force the STEM agenda in favor of one demographic over another. The participant further stated that individuals should be allowed to make their own choices regarding a field of study or career path, but certainly more can be done to show the opportunities and the paths forward regardless of gender or socioeconomic or sociocultural status. Paraphrasing one participant, “To do anything less would be counterproductive and unfair.”

An FG#3 participant identified a side issue with political messaging that called on using STEM as a tool to “remedy” ill-posed political messaging. The participant stated that state legislators would benefit by being better informed and prepared to present factual, accurate information on an issue backed by science. Particularly, data science and coherent statistics could help resolve any concern and expand an understanding of the issue without harming social groups or other stakeholders in the process. The participant also stated that it was less of an issue with foreign political and governmental leaders. The discussions then segued into an open-ended question and answer segment in which the participants in each of the educator focus groups were given an opportunity to provide additional insights. The closing results are given in the following section.

*STEM thought leadership.* The open-ended question posed at the conclusion of the educator focus groups was, “Are there any other thoughts or ideas on STEM engagement strategies you would like to share?” The question was intended to elicit
other thoughts, concepts, or ideas that may or may not have been previously covered as pertaining to STEM engagement and persistence. The additional insights and perspectives are provided below.

To begin, the FG#3 participants called for a shift in educational approach to further break down the STEM learning silos. They further believed that STEM and the humanities should be formally integrated and taught together under the curriculum, and the teachers across multiple disciplines should identify ways of collaborating more closely. STEM education was considered as important as humanities education for all students. Participants from FG#6 reinforced the message and expressed the need to eliminate the siloes. They stated that all disciplines and teachers should be better “integrated” into STEM and to work together for the benefit of student engagement. The FG#6 participants passionately expressed the “fun” going into other classrooms and giving lessons on the connections across disciplines along with explanations and examples.

A beneficial approach suggested by several FG#4 participants was to engage core teachers across STEM, history, and language disciplines and strive to affect change through improved multidisciplinary education coupled with informed career counseling. The participants further agreed that the STEM, core, and elective teachers and school counselors must partake in the dialogue to grasp the benefits of the multidisciplinary approach for informed pedagogy and career guidance (presently, the dialogue is largely among the science and math teachers). The teachers’ experiences in multidisciplinary synergies have only scratched the surface but have been positive to date and hinted at much promise in the future.
The FG#3 collective viewpoint was that the teachers cannot continue to put into practice the same model and expect different outcomes. They were aware of the disconnections among the STEM subjects and between STEM and non-STEM subjects that perpetuated siloed learning. STEM students who were largely exposed to a siloed learning environment were more likely to experience a “rude awakening” by the time they entered college, according to the participants. If underprepared for the college-level experience and the rigors of multidisciplinary group STEM learning, the students may become disillusioned and eventually switch majors or simply drop out of college.

One FG#3 participant who had taught a music elective, thought the acronym “STEAM” did not fully explain the “what” that needed to change and often felt a sense of condescension from a music teacher’s perspective. In other words, the concept of STEAM as an integrated, multidisciplinary STEM-based approach that draws on non-STEM subjects must be fortified and clarified. Just adding in the “what” (for example, the arts and the humanities) is not the answer; it must be about the “what,” “why,” and “how.” Other FG#3 participants emphatically agreed that without a substantial shift in educational approach, engagement issues and gaps would continue to persist or worsen.

Several of the FG#6 participants saw the need to tightly connect math education with other disciplines. The participants were eager to make a positive contribution by applying their expertise and experience, enthusiasm, and joy of teaching and making math an integral part of other subjects. The teachers saw the merit of applying math to a variety of non-STEM subjects and vocational trade classes including hobbies such as carpentry, construction, and other classes.
The FG#6 participants believed that the ESM High School teachers were in a good position to help fill the gaps as a step towards change. Their frontline experiences had revealed effective ways of implementing integrated, multidisciplinary education in STEM and other areas “without giving thought to it.” The teachers admittedly had to teach themselves first before extending the lessons to the students. It had been a struggle at times for the teachers to familiarize themselves with a novel multidisciplinary lesson or application at the expense of not covering core subject matter content; if problems were encountered, the benefit would be that students could share in the experience of working with the teachers towards a practical solution. The scenario served to illustrate the relationship building process between the experts (teachers) and students that emerged through multidisciplinary learning and collaboration within a context that produces positive outcomes.

Participants in FG#4 provided several recommendations to further extend the concept of STEM learning environments as a modality. It was suggested that the teachers should guide the students in building an academic and experiential portfolio highlighting real-world and hands-on project experience, practical training credentials and certifications (for example, a CISCO training certificate), college preparation courses taken, and so forth without having to emphasize state test scores. It would be about exposing the person and his/her accomplishments and their potential for growth, success, and achievement instead of emphasizing test scores and grades, which were not a true reflection of a student’s abilities. The aspects of academic rigor and passing advanced or high-stakes tests or projects requiring master-level skills should be de-emphasized, leaving that to the colleges and perhaps the workplace to cultivate.
Several of the FG#4 participants called for the teachers and school counselors to refine their soft skills—particularly communications skills, to be able to dispense effective academic and career guidance. For instance, a lack of clear communications, counseling, and coordination at strategic points in a student’s career can map into misunderstanding, misperception, and confusion. It was recommended that the STEM teachers communicate to students the realities of the rigor, discipline, and focus required of them to achieve passing grades to be eligible to apply for college, but the discussion should not end there. *Rigor* here was used in the context of teachers “walking a fine line” when it came to weighing in on a STEM-oriented student’s desire to enroll in an elective class and how that enrollment could affect a student’s grade outcome; again, the concern was over the rigor of getting through the STEM program and to be academically proficient and college-ready despite meeting the state standards.

However, the FG#4 participants felt challenged by the tensions of balancing a student’s desire to enroll in elective classes versus preparing them for the state standards test. The notion of rigor pressured the teachers into providing sound guidance on the merits of an elective class over a required class to avoid jeopardizing a student’s grade standing yet assure a well-rounded academic experience. The need for teachers to acquire the necessary soft skills to better mentor, communicate, and guide students and to ready them for college or the workforce was deemed critically important. The participants thought it necessary to intervene and dissuade students from taking certain elective classes especially if those classes were a “distraction” that could put a student’s GPA (grade point average) at risk. The points and concerns raised were driven by a
desire to ensure a conducive environment that better informed the students through improved communications as a learning modality for STEM engagement.

Adjudicating curricular needs to meet the state standards versus what was in the students’ best interests was a recurrent theme. According to several FG#4 participants, the teachers had at times been forced to consider (a) scoring adjustments to align with state grading standards and facilitate college acceptance; (b) areas of compromise of accepted grading criteria or marking standards; (c) parents’ or caregivers’ wishes for their child to not be left behind; and (d) the uncertainty of a student’s persistent-STEM-worthiness. The underlying problem, however, was whether teachers should be responsible for assuring students’ STEM proficiencies in high school to the point of producing “master class” scholars, or if it should be more about information sharing and providing guidance for them to achieve to the best of their ability. A question raised by an FG#4 participant was, “How far do we as teachers need to take this?”

A combination of the ongoing pressures of scripted state testing, employing test scores as the benchmark of achievement, teacher assessments, resistance to reforms, and the slow pace of change have created stresses for the students and teachers alike. Continually coping with the stresses have led to burnout, apathy, disengagement, shutdown, or retreat. The FG#4 participants felt that it should not be on the teachers alone to turn students into STEM field masters. Much of the responsibility to succeed and thrive beyond high school should reside with the students who have their entire careers ahead of them albeit, others should assist in their journey including higher education.
According to several of the participants in FG#4, without significant reforms the rate of teacher attrition will increase, and the students will lose out on valuable academic and career opportunities. The change would affect learning environments, modalities, and policies including a shift in responsibilities along with a restatement of academic goals. The inability to reform current processes has been a disservice to students and a deterrent to STEM engagement. A suggested approach to alleviate the problem was to change the scholastic grading system by eliminating state testing and scripted programs, which some believed was outdated and set the academic system up for failure from the beginning. The recommended shift in strategy was to avoid over-dwelling on the rigor in high school to meet the testing standards and put the achievement of master class skills on the shoulders of higher education, while delivering reliable college preparation content in secondary school. Adopting progressive reforms would achieve a better balance in STEM engagement in the near term and prepare the way for incremental improvements over time.

The gap between the high school senior year and the college freshman semester raised another question on multidisciplinary education. Participants in FG#3 cited the success of such programs at the State University of New York College of Environmental Science and Forestry (SUNY ESF). One of the FG#3 participants familiar with the ESF program asked, “What had ESM High School done that ESF did not or had done differently to ensure a successful model?” The participant suggested that any educational shift should focus on answering that question and consider adapting ESF’s model.

The same FG#3 participant cited higher education itself as contributing to the STEM gap. The participant stated that although the collegiate culture had been steeped
in tradition and fostered equal opportunity learning, it intentionally or otherwise promoted the populist notion of *elitism*. To somewhat illustrate the point, a participant noted the disparities that exist both in pay and workload between adjunct professors and their full-time associate or tenured counterparts; adjunct professors tended to have a higher load at a lower salary.

In the opinion of one FG#3 participant, the pristine image of colleges as venerable institutions of higher learning has dulled somewhat. Its image has changed to one of promoting self-interests, creating inequity, and losing sight of the mission, said the FG#3 participant. The participant went on to further say that colleges had become increasingly profit conscious, capitalistic, and fundraiser-driven which casted a less than flattering light on the institution and its motives, considered truer today than ever. Two of the FG#3 participants were adamant on the need for universities to rid themselves of a self-perceived *elitism* that assumed the *students need them more than they need the students*. Indeed, the factors identified above may be working against (STEM) education reform.

Participants in FG#3 further suggested reexamining the *sink or swim* mindset in higher education through the lens of STEM attrition. The goal was to better understand why some STEM students were more college ready than others and what the secondary and higher education institutions could better do to control downstream attrition. For instance, the secondary schools expected higher education to shoulder more of the burden of assuring academic readiness on top of career readiness. On the other hand, higher education expected secondary schools to produce master class students, thus revealing a gap whereby blame is cast for high expectations versus not doing enough.
To admonish the secondary school for not doing enough in precluding disenchantedm with STEM early during the college term gains little in addressing the issue. It becomes a question of why and what can be done at that point. Higher education should do more at implementing an action plan and work with the student on upstream academic interventions or viable alternatives and avoid finger pointing back to the secondary institutions on causality grounds. The lessons learned can be used to advise the secondary institution of what more they could reasonably do to forestall downstream STEM disengagement and attrition. The implication here was to improve dialogue and coordination for the students’ benefit.

The FG#3 participants offered further recommendations on ways to reinforce the STEM pipeline at the secondary school level aimed at students who were unsure about their STEM fit or commitment as they entered college. Their recommendations included (a) building trusted relationships for open dialogue on STEM options; (b) exposing and enabling STEM opportunities; (c) teachers heeding the voices of students as they articulate their interests and doubts; and (d) giving the students clear and informed choice in the matter. A participant in FG#3 begged the question, “How do we build a culture of inclusivity and show students that we want them to succeed in STEM fields?”

According to another FG#3 participant, the state and the school district leaders expected the ESM High School teachers to become well versed in the myriad educational statistics including those on international STEM rankings and student attrition rates. They were then asked to identify corrective actions to mitigate deleterious trends. The teachers and institutions were also expected to devise plans for institutional cultural change using the accepted models of Couros (“21st century innovation mindset”), Dweck
For example, the growth mindset is premised on the fundamental idea of coping with failure and yearning to succeed by improving oneself. The strategies for coping with failure and self-improvement fall well within the bounds of STEM pedagogy especially regarding math learning. Figure 4.3 shows the basic tenets of the fixed versus growth mindset. In the growth mindset, the traits shown in Figure 4.3 are nonrigid, are adaptable, and can change with one’s experience along with other learning stimuli that in turn, influence behavior traits. Those with fixed mindsets are fearful of challenges and often feel the need to prove (not improve) themselves or even retreat when the going gets tough. Those with growth mindsets are ready to embrace the unknown and face risk towards a positive learning outcome even if it means failing along the way. Figure 4.4 illustrates the methods of encouraging those with fixed and growth mindsets; the growth mindset is open to learning and improving whereas the fixed mindset is more cautious and reserved.

The Innovator's Mindset on the other hand, is aimed at encouraging educators and school administrators to inspire their students to become curiosity seekers, forward-thinking leaders, and agents of change. The idea here is that innovative teachers and progressive administrators will breed creative, innovative students. It is about creating a culture of creativity, innovation, and empowerment for positive change by connecting with students to understand their needs, connecting with other educators and experts to expand vision, and connecting with administrators and influencers to create opportunities for innovation and change of the types shown in Figure 4.5. The Inspiring Education
Wheel illustrates how to focus subject/discipline areas in a way that matches any one of three key objectives: entrepreneurial spirit, engaged thinker, and ethical citizen. The wheel covers the areas relevant to STEAM learning.

Figure 4.3. The fixed mindset versus the growth mindset. A growth mindset is premised on the fundamental idea of coping with failure and yearning to succeed by improving oneself. The strategies for coping with failure and self-improvement fall well within the bounds of STEM pedagogy. In the growth mindset, the traits shown are nonrigid and adaptable and can change with one’s experience along with other learning stimuli that influence behavior traits. Adapted from “Mindset: The New Psychology of Success,” by C. Dweck, 2016.

Although the models were often used to define the requisite steps for affecting systemic change, they were not always systematically and consistently put into practice at the level of higher education. Hence, another contributor to the STEM gap emerged
when such models were not put into practice or if their impact was local and sporadically felt, rather than widespread and consistently applied. A call to action was made by one FG#3 participant to implement, monitor, and refine a meaningful process for full impact and measure instead of a superficial plan that barely moves the needle on progress.

Figure 4.4. Carol Dweck revisits the ‘growth mindset.’ The figure illustrates methods of encouraging those with fixed and growth mindsets where the growth mindset is open to learning and improving whereas the fixed mindset is more cautious and reserved. Adapted from Education Week. Retrieved from http://www.edweek.org/ew/articles/2015/09/23/carol-dweck-revisits-the-growth-mindset.html?cmp=cpc-goog-ew-growth+mindset&ccid=growth+mindset&ccag=growth+mindset&cckw=%2Bgrowth%20%2Bmindset&cccw=content+ad&gclid=Cj0KEQiAnvfDBRCXrabLl6-6t-0BEiQ_AW4SRUM7nekFnoTxc675qBMSJycFgwERohguZWVmNDCsUg5gaAk318P8HAQ
FG#4 participants offered a different closing perspective by highlighting the changing role of high school counselors in STEM outreach and student engagement especially during their senior year. According to the participants, counselors have traditionally played a pivotal role in guiding a student’s career decision, but their role in this regard had significantly shifted in recent years. The school counselor’s role had become more one of handling social-emotional issues; informed career guidance had
become a lesser priority, thus adding to the STEM gap. The situation begged the question, “Who is filling that gap today, or who is in charge of career guidance?”

The STEM teachers have now taken on the role and the major responsibility of STEM career counseling for students they know or teach, but concerns exist over other students who are outside the STEM teachers’ spheres of influence. The situation begged yet another important question, “Who will guide them and how best to guide them?” The combined lack of informed, engaged career counselors and the absence of reliable, consistent, and informed STEM career guidance for students at ESM High School, was identified as a significant contributor to the STEM gap. The FG#4 participants felt that virtually no one else at ESM High School was providing reliable, consistent, and meaningful career guidance.

The FG#4 participants agreed that the students’ lack of direction has been a factor in STEM disengagement, considered from the teacher as a counselor perspective. The myriad electives, lack of direction given to teachers, sporadic coordination between administration and teachers, and the resultant distractions have exacerbated the situation to the point where guidance is incomplete, uninformed, or disjointed. The teachers were not always fully prepared or trained to give such counseling. As one participant stated, “There are too many moving parts that are not all coordinated or understood.” The problem persists despite the ESM counselors having the students fill out packets and questionnaires on college and career readiness.

According to several participants in FG#4, the STEM outward messaging was confusing and conflicted, and the goals of recruitment lacking in terms of workforce preparedness. The general feeling was that schools and industries were forcing the
STEM agenda on students and were sending the message that STEM was the only path worth taking in pursuit of a rewarding career. Further compounding the messaging problem were efforts to downplay the importance of STEM trades that were deemed to be at least as competitive and rewarding as college STEM degree programs and outcomes in view of investment, advancement potential, salary, risk versus reward, and overall job satisfaction. Several participants in FG#6 felt the high school tended to emphasize STEM college paths over trade/vocational opportunities.

An FG#4 participant gave an anecdotal account of a student who earned a college degree in a STEM field and then accepted a lucrative offer at the National Aeronautical and Space Administration (NASA) in Houston. The individual eventually transitioned from a degreed STEM career in rocket science for NASA to a STEM trade job in aircraft maintenance engineering for American Airlines because of an increase in pay and a less demanding work schedule. The story illustrated the realities of life and career not matching expectations. According to several of the FG#4 participants, the dilemma could have been attributed to earlier uncertainty and uninformed decisions over the “hype” of what was thought popular or important at the time (that is, a prestigious position at NASA).

Although academia and industry had often pushed for students to earn a 4-year college STEM degree, some participants in FG#4 cited the advantages of pursuing a 2-year certification program while working at a trade job. For example, utility or nursing trades do not necessarily require earning a degree at a 4-year institution. A STEM trade opportunity reduces the amount of personal and financial investment with the advantage
of tapping into an employer tuition assistance program while benefiting from a competitive salary and compensation package.

Such *win-win* scenarios were in direct competition with the traditional 4-year college and degree programs. The changing views and other tangible benefits such as overtime pay, greater time management, less personal commitment and financial investment, opportunities for hands-on activity, self-satisfaction, greater peace of mind, and so forth make STEM trade jobs an attractive option. It is about a new concept of STEM that is growing in popularity and demand.

The participants across the three focus groups generally agreed to a multiprong strategy for increasing STEM engagement. The strategy fundamentally built on the premise of culturing STEM affinity and implementing a forward-thinking STEM pedagogical model. It respected the students’ rights to choose in accordance with their personal interests and beliefs rather than have STEM foisted on them at the exclusion of all else. Further, teachers and counselors should deliver informed guidance to students and not discourage their dreams or tell them what they *should* or *should not* do as a career choice. Indeed, the message that the STEM community had sent in the past was considered somewhat heavy-handed and biased and is an Achilles’ heel that will only widen the STEM gap, according to the participants. A more effective strategy, as a synthesis of the participants’ ideas and recommendations, emerged as follows:

- Avoid exaggerated STEM messaging as a panacea to curb STEM workforce attrition at the expense of duly considering other career options—misleading others by the “hype” or influencing them to stray from desired career paths;
- Expose students to multidisciplinary possibilities to “see” the connections;
• Encourage students to follow their own path while helping them build on their interests and leveraging their strengths;

• Intertwine students’ outside interests (hobbies like music, game design, and so on) with classroom STEM activities and build on curiosity, not technology;

• Identify and fill learning gaps (such as connecting music and STEM) as a holistic approach to developing the well-rounded student;

• Remain open to what students seek regarding college/career advice; and

• Cultivate emotional intelligence—the sensitivity to social/emotional cues.

Several FG#4 participants added that ESM High School culture seemed adult-driven and somewhat less oriented towards active enablement of students’ career paths or choices after graduation. The school seemed to be concerned with the teachers and their experience, exposure, credentials, and the school’s overall community image and standing which had shed some additional light on the possible disconnects in STEM paths after high school. If the encouragement toward STEM is weak or sporadic, then engagement suffers.

One participant in FG#6 expressed concerns about human and machine learning using STEM versus STEAM as a learning base. The participant was concerned about how societal biases regarding sex/gender, race/ethnicity, and faith/religion were being implicitly coded in machines and artificial intelligence (AI) systems, and how the present study could help in understanding the issue. The participant stated that if the implicit issues were not properly dealt with, then the AI-driven systems and machines would likely reflect those same biases unless measures were taken to recognize and “process out” or expunge those biases. The researcher prompted this discussion by offering the
metaphor of pure logic is to STEM as logic tempered by emotion is to STEAM, thus underscoring the potential importance of multidisciplinary strategies in an AI and machine learning context.

Finally, another FG#6 participant reiterated the need to eliminate state standards testing and especially the state Regents exams altogether. The participant viewed the exams as detrimental to the STEM and STEAM agendas and a disservice to students on a wide scale. Indeed, it was felt that many policy reforms in STEM education were needed before true change can take place and the benefits can be realized. The overall conclusions of the study and a summary follow.

**Conclusions**

The above findings from the data analyses across the student focus groups separate from the educator focus groups were then aggregated and synthesized to distill the global themes, findings and conclusions aligned with the research questions. The aggregated findings showing the key themes and outcomes of the study are listed in Table 4.4. The synthesis confirmed many of the contributing factors to the STEM gap that were identified in Chapter 2 and pointed to areas of concern for STEM engagement. The analysis also identified several new and unexpected findings that were undocumented elsewhere, thus filling a gap in the research corpus.

Several core findings and conclusions were revealed that established the foundation for the study as follows. First, increasing STEM engagement and persistence begins by paying close attention to two important factors. One factor is a student’s STEM affinity, and the other factor is the academic (or the organizational) system’s
willingness to build and nurture STEM capacity beyond what standard protocols advise. This is further explained as follows.

**Highlights of key findings and conclusions.** To say that an increase in STEM recruitment is necessary is simply insufficient and sends a confusing message. The “why” and “how” of the message are not well understood. Federal, civic, public, and private organizations have propagandized the urgent need to fill STEM jobs and improve America’s global STEM ranking at any cost but have often overlooked the STEM affinity factor.

STEM affinity—a student’s predisposition to STEM—is related to three key factors. The actors include (a) the students’ desires and expectations, (b) the alignment of the STEM pipeline in meeting specific STEM field demands, and (c) whether the schools are prepared to handle the specific demands and undertake effective pedagogy, marketing, and recruiting campaigns. Problems arise when the STEM message is overpowering, and the inherent STEM affinity is weak.

To be effective, STEM pedagogy must fundamentally build on existing STEM affinity and nurture that affinity in a non-disjointed way. It is less about convincing everyone about the merits of STEM and jumping on the STEM bandwagon and more about curbing attrition by building capacity based on those who are already STEM-disposed (for instance, one who is technology motivated to begin with). Therefore, the aim is to appeal to students with at least a moderately high STEM affinity. Unsurprisingly, affinity-building starts at a young age. Non-STEM students who gravitated towards STEM tended to be outliers.
<table>
<thead>
<tr>
<th>Research Question (RQ#)</th>
<th>Contributors to STEM Gap Widening and Trends Drawn from Aggregated Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>RQ1: From the student’s perspective, how does participation in a STEM learning program stimulate or deter interest in pursuing a STEM major in college or as a career choice?</td>
<td></td>
</tr>
</tbody>
</table>

**STEM Affinity:**

“STEM” is ill-defined and tries to appeal to everyone instead of focus on those with high STEM affinity.

STEM outreach and marketing are unprepared to appeal to students with low STEM affinity.

**Institutional STEM Curriculum:**

Using an outdated STEM-only learning model based on a rigid, formulaic siloed curriculum.

STEM pedagogy that is inconsistent and discontinuous, and STEM messaging that is often “forced.”

Lack of multidisciplinary, integrated, and practical STEM problem solving activities in a group setting.

**STEM Learning Environments and Strategies:**

Lack of a connective STEM plus fine arts (STEAM) “fabric” constrained by the state standards and an uncertain rollout strategy.

Lack of a nurturing STEM learning environments including teacher mentorship that exposes students to real-world team settings, internships, and tours of engineering/technology companies to inform college/career decisions.

Absence of creative (out-of-the-box brainstorming) and hands-on problem solving that exploits multidisciplinary synergies to address purposeful, real-world needs and that evoke novelty and are personally gratifying.

A failure of the curriculum to exploit the natural relationships or connections between STEM and the fine arts to evoke self-expression, creativity, and innovation.

Lack of teacher motivation or engagement in delivering STEM content and showing multidisciplinary connections.

Ineffective exploitation of multimodal (visual and tactile or hands-on) learning to instantiate STEM persistence.

Failure to exploit the fine arts to deal with the rigors of STEM providing an “offramp” to understand and appreciate the inherent scientific context and mathematical structure and artistic content and relationships.

**STEM Marketing and Messaging:**

STEM outreach fails to build on early exposure to STEM because programs lack multidisciplinary diversity and do not match students’ interests.

Forceful STEM messaging puts college-based careers first while devaluing vocational/trade-based careers; failing to promote college/professional and vocational/trade career pathways in a balanced way.

Limiting one’s choice in terms of outside expectations of pursuing a traditional STEM career.
Research Question (RQ#)

Contributors to STEM Gap Widening and Trends Drawn from Aggregated Findings

Organizational and Individual Factors:

Organizational inability or unwillingness to build and nurture STEM capacity beyond the limits imposed by state curriculum standards by failing to employ novel STEM pedagogical best practices.

“Systemic” multiorganization inertia against implementing a near-term, progressive STEM strategy and failing to keep pace due to protracted inaction.

Peer influence on one’s decision to pursue a STEM college/professional or a trade/vocational career path.

RQ2: From the perspective of the educator, how do current STEM programs contribute to or detract from STEM persistence after high school, during college, and as a career choice?

STEM Affinity:

Failure to focus on students with high STEM affinity and academically borderline in STEM (students and teachers viewed this similarly).

Not culturing STEM affinity and not implementing a forward-thinking STEM pedagogical model.

Institutional STEM Curriculum:

Perpetuating a legacy of siloed learning burdened by NYSED constraints; the state education system cultivates a siloed STEM learning mindset yet points to the need for a progressive curriculum and creative lesson planning.

Inflexible, bureaucratic state education system not prone to enact curricular change; STEM curriculum is encumbered by NYSED standards that limit teachers’ latitude in implementing novel strategies.

Dichotomous policies and messaging at the state level lead on STEM programs that are implemented nonuniformly, disjointly, or incompletely due to inconsistencies in how standards are applied grade wise.

The focus on meeting state regional test standards and requirements is a major gap contributor; state testing is considered outdated and sets the academic system up for failure.

A combination of the ongoing pressures of state testing, using test scores as the key measure of achievement, teacher assessments, a lack of endorsement of current practices towards change, and a resistance to progressive reforms creates stresses for students and teachers alike leading to attrition.

Inaction to replace standards competency-based pedagogy with application/outcome-based pedagogy.

Fear of jeopardizing STEM education grant funding by rolling out novel (creative) programs that could be deemed too risky or out of scope according to the NYSED leadership.

STEM Learning Environments and Strategies:

Not ensuring continuity in STEM learning and understanding multidisciplinary synergies (thematic threading) within and between STEM and other subjects.

Slow progress in pivoting towards a STEAM fabric via an integrative, multidisciplinary pedagogy that infuses the arts and humanities to build soft skills combined with a content driving curiosity approach.

Institutional inertia coupled with staff logistical and time constraints limiting the rollout of multidisciplinary, application-based curricular models meant to assure continuity in experience from high school to post-graduation.
Research Question (RQ#)

Contributors to STEM Gap Widening and Trends Drawn from Aggregated Findings

Subject-class territorialism coupled with a fear of change.

Unsuccessfully integrating math and not effectively connecting math and the fine arts like music.

Forcing artificial intersections of the STEM and arts domains could “dilute” STEM’s impact.

Not showing meaningful multidisciplinary connections via concrete examples or practical problem sets.

Lack of novel interventions to stimulate creative independent/team learning and critical thinking by introducing non-STEM (arts and humanities) as part of a progressive, impactful STEM curriculum providing for rich contexts.

Lack of a “common planning” tool to address interdepartmental disjointedness on behalf of meeting STEM goals; not encouraging cross-disciplinary coordination and support amongst educators meant to bridge disparate domains to expand frames of thought and create new opportunities to fill the gap.

Lack of PBL protocols that make it difficult for students to acquire and integrate soft skills in STEM.

Failure to expose students to real-world problem-solving opportunities inside and outside the classroom.

A “one size fits all” (monolithic) and inflexible STEM pedagogical approach that hinders customizing programs to meet students’ needs or interests and fails to exploit self-motivational theory to stimulate one’s creative potential.

Spectrum of learning-disabled, behavioral, and other student categories that dictate instructional needs.

Lack of multimodal content delivery via visual, tactile, and experiential means using real-world problems.

Setting nonrealistic goals and expectations, discouraging experimentation/risk, and no failure-coping safety net; lack of support for students in confronting real-world challenges, making informed decisions, and culturing them to embrace and recover from failure.

Failing to teach students to adopt a risk and reward mindset, inspire a culture of curiosity and the practice of inquiry, and cultivate an institutional growth mindset via entrepreneurial principles.

A pedagogical environment that fails to tap into optimal team collaboration and group size guided by teachers; not fostering an integrated product team mindset early on for team building.

All access to an overabundance on technology at virtually anytime and anyplace feeds into instant gratification and an inability to manage failure and expectations; managing technology distractions that can reduce attention span.

School counselors who fail to provide sound career guidance, enable informed career decisions, encourage individual passions, and share the STEM vision by articulating the possibilities, options, and opportunities to students and their parents/mentors to secure STEM engagement; a lack of clear communications, counseling, and coordination at strategic points in a student’s career contributes to disengagement.

STEM Marketing and Messaging:

An ill-defined STEM agenda that is absent of cross-disciplinary associations and calls into question the effectiveness of today’s outreach tactics on long-term engagement.

Over-hyped message that STEM is the only path worth taking focusing on a college path vs. vocational/trades path; over-propagandizing the STEM agenda in a way that could disengage interest.
Contributors to STEM Gap Widening and Trends Drawn from Aggregated Findings

STEM outward messaging that is confusing and conflicted, and where the goals of recruitment are lacking vis-a-vis workforce preparedness.

Nonoptimal marketing, structuring, and scheduling of STEM classes and electives forces students to choose from myriad options and become confused or overwhelmed; failure to crystallize the messaging and a lack of clear marketing/advertising to raise students’ awareness increases confusion, anxiety, and disengagement.

Not empowering students to make independent academic and professional career choices that build on their interests; pushing the STEM agenda at the exclusion of all else and discouraging their interests.

Organizational and Individual Factors:

Promulgating the notion of STEM as elitist—only for those who qualify or meet certain requirements.

Not informing students’ parents and families of STEM options for 2- or 4-year colleges, vocational trades, scholarships, internships, job market and timelines, and associated risks/benefits.

Not connecting STEM programs with industry and business workplaces and failing to increase the number of internships, corporate scholarships, and college credits to resonant with students’ interests.

Failing to recalibrate the notion of STEM inclusive of technical vocational/trades and enable choice by weighing cultural values; polarizes technical trades from mainstream STEM opportunities.

Perpetuating stereotypes about the rigors and demands of STEM fields compared to non-STEM fields.

External influences (risk vs. reward, expectations and demands, stress or anxiety, and negative outcomes) especially for students with low STEM affinity who are pipelined into STEM fields.

High expectations on high schools to produce “master class” STEM scholars in high school and instead, shifting the responsibility to colleges while delivering reliable college preparation content in high school.

Not proactively implementing proven best practices (mutual trust building, assessing lesson effectiveness, active student outreach, and providing a nurturing support environment).

Teachers not adapting their skills in multiple subjects to shape the new STEM pedagogical landscape.

Not recruiting industry experts for practical STEM training experience to inspire and motivate students.

RQ3: From the standpoint of students and educators, why might STEM persistence or sustained STEM interest upon/after high school graduation be on the decline?

Institutional STEM Curriculum:

Failure to eliminate a monolithic STEM pedagogical model; a constrained educational curriculum is counter to unfolding a progressive STEM learning model; maintaining the status quo in rigid STEM educational practices will only exacerbate the disparities in STEM outcomes.

A “no child left behind” mindset that teaches students to “trust the process,” follow the rules, “regurgitate” the curriculum, avoid risk, and focus on achievement to meet the NYSED standards and Regents test/grading system.

Standardized testing—prioritizing efforts to prepare students for the state Regents tests and the lag in reforming state education standards are deemed barriers to true education—creates a culture of fear and failure that is psychologically stressful and unhealthy and could deter students from pursuing a college STEM major or career.
Non-integrated (siloed) STEM curriculum with low STEM program diversity; non-impactful STEM programs that disillusion students or fail to meet expectations.

Uncertain priorities for strategic investment—many ideas have been conceived that await adoption for “mainstream” implementation, but the right STEM programs with high returns on investment and allowing time for the programs to take effect and for the gap to close are at issue.

Inconsistently delivering a stable, focused STEM program with a flexible set of options or electives and not enabling students a choice leading to uncertainty, complacency, and apathy.

Over-paced series of program trials and STEM information overload—detrimental to STEM engagement.

The “disjointedness” of programs over time leading to a confusing and bloated STEM education landscape, loss of focus, unachieved goals, and eventual teacher burnout and student disengagement.

STEM Learning Environments and Strategies:

Lack of a nurturing STEM learning environment and motivational teachers; teachers failing to consistently nurture opportunities, build skills and confidence, instill empowerment and pride through accomplishment, and create pathways that move the students in a direction toward STEM interest and career success; complacent teaching style or boring content delivery in the classroom breeds student boredom or apathy.

Lack of collaborative group settings that allow for independent/individual study.

No access to realistic workplace or natural laboratory settings to expand the students’ experiences.

Lack of exposure to practical, real-world projects that show the math connections across multidisciplinary subject domains as part of a process to adapt a college-level applied learning mindset.

Disconnection between STEM and the humanities and failing to make interdisciplinary connections and “stretch” the curriculum when time and opportunity permit; the teachers are unable to effectively make interdisciplinary connections because of state curricular constraints and are losing touch with teaching the lesson fundamentals.

Lack of state-level adoption of new ideas for teachers across multiple disciplines to jointly craft customized content modules and to deliver educational products that supersede the rigid state test-based standards; cooperation lacking by the state education agencies to pass progressive STEM policies and practices to prevent STEM erosion.

Failing to show math’s relevance to real-world applications and across multiple disciplines to make it less abstract and to teach students important life and career skills.

Lack of knowledge and skills to build math confidence, and not understanding the link between math anxiety and STEM engagement; failing to acknowledge that a less than student-friendly curriculum combined with a fear of failing the state Regents tests exacerbates math anxiety.

Teachers failing to intervene to assist students in overcoming intrinsic math anxiety and coping with failure; also, not implementing interventions at the elementary/middle school level to train staff in effective math confidence building techniques to help younger students see math, failure, and persistence through a different lens and enable them to become more self-driven to manage their fears.

Failure to moderate students’ dependence on tools and electronic aids to accomplish basic mathematical tasks and conquer instant gratification to prevent disengagement.
Research Question (RQ#)

Contributors to STEM Gap Widening and Trends Drawn from Aggregated Findings

Creating “artificial” or forced interdisciplinary connections that do not naturally fit together.

Lack of training in how to embrace challenge and manage failure to build a “STEM-hard” character.

Lack of informed career guidance coupled with not exercising choice in navigating the “unknown.”

Diminishing students’ right to choose leads to retreat and falling into the trap of focusing on self-interests and overlooking the larger picture; students who disengage from STEM may convince themselves that overachieving to get into college is unnecessary and will be less incentivized to hone competitive skills.

Pressuring young students into STEM and disabling their ability to make their own choices (thought to make a significant difference in true and persistent STEM engagement).

Ill-prepared high school STEM graduates who meet the minimum state standards—the rigors of the college STEM experience could entice them to switch to a non-STEM major or drop out altogether.

STEM Marketing and Messaging:

- Poor marketing or advertising of STEM offerings, myriad non-STEM classes, and conflicting schedules.
- Inconsistencies in “capturing” STEM interest at a young age and maintaining continuity of STEM programs prior to and during the high school years.
- Forcing rather than nurturing STEM engagement at a young age and empowering informed free choice.
- Failing to expand opportunities that match specific interests or needs in support of STEM career pursuits.

Marketing strategies and inward messaging that foster misconceptions setting STEM students up for failure upon entering college; high school students—a vulnerable group—may be unsure of their college/career path and may have been encouraged or pressured into pursuing STEM, and where non-STEM pursuits are frowned upon.

STEM marketing and outreach non-inclusive of disadvantaged, underserved, or underrepresented groups and that fail to build on aspiration—perpetuating elitist and socioeconomic and sociocultural stereotypes.

Forced marketing to fill an artificial quota for females in STEM; the constant “STEM for girls” marketing blitz, which can have a polarizing effect on STEM attitudes, and the resultant pressure on females is backfiring by discouraging them from naturally and freely choosing fields or professions that they want to pursue—failing to build upon an individual’s passion, talent, fit, and choice; casting doubt by questioning females about their choices when it comes to STEM vs. non-STEM fields or pursuits.

“Hyping” STEM as a panacea for workforce preparedness where STEM education is ill-defined and the strategies for developing and implementing high-impact STEM programs are uncertain; the messaging is vague and open to interpretation, leading to a wide array of programs that on one hand, are beneficial in terms of diversity, but on the other hand, are confusing and inconsistent with varied expected outcomes.

Barraging students with conflicting messages as “STEM is harder than other subjects,” or “grades are key,” or promulgating misconceptions like STEM is reserved for the elite, or advertising STEM to only those with the right credentials may “flip the switch” in engagement between high school graduation and the first year of college.

Organizational and Individual Factors:

- Lack of positive family influences and peer encouragement.
Family influences driving students to achieve good grades at any cost mainly to qualify for STEM college scholarships and reduce financial burdens.

Perpetuating stereotypical beliefs on the expected roles of males and females or underrepresented groups.

Not exposing females at a young age to STEM content.

Failure to empower females to make their own choices in STEM marketing strategies.

“Pushing” females into STEM against their will or not supporting their decisions to split off into STEM and/or non-STEM classes and customize the program to appeal to their specific interests.

Negative peer influence on pipelining females in STEM knowing it is male dominated and competitive.

Lack of informed, prepared school counselors offering effective guidance on the realities of STEM opportunities; failure to dispense authentic, informed guidance to students about STEM opportunities and not enabling them to autonomously make choices tempered by expert guidance.

Failing to cultivate a “unicorn” mindset as a workforce issue by embodying the intersection of the science/technology and art/design domains (knowing people are STEAM creatures, not STEM creatures).

Career development strategies that focus on salary or economic incentives rather than balancing other factors including self-efficacy, self-improvement, advancement, and positive social contributions.

Higher benefit-to-risk ratios for non-STEM majors in terms of competitive salaries and benefits, reduced commitment and scholastic intensity, high job demand, and lower stress.

Multiple “systemic” issues and institutional shortcomings that favor (or deny) STEM educational opportunities based on privilege, class, wealth, and power—a social injustice; lack of action or not taking more aggressive steps toward change will widen the STEM gap and contribute to middle class erosion as a socioeconomic issue.

Social Justice Detractors (Gender, Underserved/Underrepresented, Socioeconomic, Sociocultural):

Perpetuating gender-bias stereotypes and failing to cultivate associations between strength and empowerment and being a female in STEM.

Not exposing females to STEM at a young age to establish a foundation to build upon in their later years.

Questionable tact of challenging one’s choice of a STEM or non-STEM field or pursuit creates doubt.

Laws that mandates companies meet hiring quotas across gender, race/ethnicity, and other socioeconomic and sociocultural criteria—creating conditions that could lead to the hiring of unqualified candidates and causing “workforce tensions” (an imbalance in workforce supply and demand of certain types of skilled labor that could be difficult to fill, potentially widening the STEM pipeline gap), rather than hiring based on talent and capability—an ill-conceived process that is prone to failure because it neglects the science and the labor force data to launch a truly informed campaign.

Failure to closely examine the relevant socioeconomic factors on STEM engagement—the relevant socioeconomic issues and contributing factors are tied to federal and state legislation; failing to recognize that the socioeconomics outweigh the gender-bias issue via a greater number of class and race issue that such groups continue to face.
Contributors to STEM Gap Widening and Trends Drawn from Aggregated Findings

RQ4: From the perspective of students and educators, how can interest in pursuing a STEM major in college or a STEM career be increased?

Institutional STEM Curriculum:

Maintaining the status quo of legacy, siloed, theoretical classroom learning that disconnects the STEM subjects and isolates non-STEM subjects leading to a “rude awakening” upon entering college.

Unwillingness of school leadership, administration, and STEM teachers to push for reforms in current policies, procedures, and best practices that would help improve STEM engagement upon graduation.

Lack of substantial STEM curriculum reform or educational shift at the state and district levels to eliminate legacy siloed learning structures to prevent disengagement and gaps from persisting or worsening; failure to reform the state testing standards and Regents exams or eliminating the exams altogether to mitigate the STEM gap; the exams are detrimental to the progressive STEM agenda and a disservice to students on a wide scale.

Failure to fill the STEM gap by not refining, implementing, and monitoring a realistic, well-crafted plan for full impact and measure instead of a superficial one that barely moves the needle on progress.

Not effectively engaging the core teachers across STEM, history, and language disciplines to strive for change through improved multidisciplinary education coupled with informed career counseling.

STEM Learning Environments and Strategies:

Lacking to clarify and fortify the concept of STEAM as an effective integrated, multidisciplinary STEM-based model—failing to integrate and teach STEM and the humanities together under the curriculum and develop a plan for the teachers across multiple disciplines to collaborate for the benefit of student engagement closely and effectively; and failing to show the connections across disciplines using clear explanations and practical examples.

Failing to show connections between math and other disciplines including vocational/trade education.

Failing to unleash the students’ fundamental desire for knowledge and how to apply it, or the notion of balancing in-class, theoretical learning and research against practical experience and applied theory.

Lack of outside-class or cocurricular activities including clubs that help build relationships and expand awareness of multidisciplinary connections in natural contexts that ultimately benefit the more rigid classroom setting; experience better enables career decisions through enhanced awareness.

Not taking students outside their comfort zone and instilling confidence in self-achievement regardless of the outcome and failing to eliminate popular distractions (social media) to focus their attention.

Denying an environment for autonomy or the freedom to learn coupled with technology-based internships that build confidence via natural and practical learning to see the facets of STEM “in action, in the field.”

Failing to correct for inefficiencies in the (small and large) group/collaborative process, mix, and dynamics and not exploiting project/goal-based learning models via a facilitator tier across multiple projects that gives the students “ownership” of their individual projects and engages and invests them in project outcomes and manage failure.

Not giving the option to high school STEM students for individual discretionary time before engaging in any group collaboration to effectively convert the “individual” mindset into a “group dynamic” mindset.

Failing to teach the soft (social) skills needed for effective communication and group interaction, which are characteristic of industry integrated product team environments.
Research Question (RQ#)

Contributors to STEM Gap Widening and Trends Drawn from Aggregated Findings

STEM Marketing and Messaging:

Lack of expanded advertising of the STEM program with a clear definition and outreach to elementary/middle school grades (presentations and visits to describe traditional STEM/STEAM and specialized programs).

Students not actively marketing or promoting the STEM program conveying their experiences and knowledge gained, friendships formed, and the many fun group activities and learning opportunities.

STEM marketing failing to address comment and recurrent concerns over gender parity, equity, equal opportunity for high-paying jobs, reward and fulfillment, financial security, and personal happiness.

Lack of STEM messaging that career decisions should not be based solely on personal interests or desires but should balance multiple factors (job demand, advancement opportunities, salary, and so on).

Ineffective marketing that fails to advertise STEM as an enabler for competitive skills development in fields that engender social justice and social equality touchpoints.

STEM marketing failing to address other social justice considerations such as technology’s role in society for improved quality of life; opportunities and incentives for underserved groups; philanthropy and humanitarian needs; contributions to job growth and societal financial health; and corporate or other organizational outreach.

Perpetuating barriers to STEM entry through mixed messaging which states that some STEM fields are more competitive than others when combined with socioeconomic or sociocultural factors or indicators.

Organizational and Individual Factors:

Failure to ensure continuity in teacher/counselor/mentor support systems and informed guidance; failing to prepare students for college and the rigors of multidisciplinary group STEM learning causing disillusionment and switching majors or dropping out of college. (a major gap).

Failure of school counselors to provide more informed guidance instead of primarily managing social-emotional student issues daily (career guidance has become secondary); instead, career guidance is now routinely delivered by educators; the teachers are not always prepared to deliver counseling and concerns are over students outside the STEM teachers’ spheres of influence (the combined lack of informed, engaged, and dedicated career counselors and the absence of reliable, consistent, and informed STEM career guidance for students was highlighted as a significant STEM gap finding independently corroborated by the teachers).

Delivering incomplete, uninformed, or disjointed academic and career guidance exacerbated by the myriad electives, lack of direction given to teachers, the sporadic coordination between administration and teachers regarding counseling, and other distractions.

Lack of informed counseling balancing other vital factors in STEM career decisions beyond salary/compensation and personal or aspirational interests, including market demand and willingness to “invest” in the process.

The college/university institution itself either intentionally or inadvertently promoting an image of elitism and promulgating a culture of inequity that adds to disenfranchisement.

Higher education failing to proactively ensure that students are successful in STEM or have viable alternatives; lessons learned can advise high school institutions of factors at the secondary level contributing to disengagement.
Contributors to STEM Gap Widening and Trends Drawn from Aggregated Findings

(ESM High School) needing to further shift from an adult-teacher-driven focus to a more student-career-driven focus; engagement suffers if student encouragement towards STEM is weak or sporadic.

Social Justice Detractors (Gender, Underserved/Underrepresented, Socioeconomic, Sociocultural):
Not cultivating STEM interest and a resident support system to nurture the desired skill sets and to expand the ecosystem of opportunities for underserved/underrepresented/disadvantaged social groups.

Females not taking a stand on the growing number of women entering the STEM fields and breaking through the “glass ceiling” in response to disparity issues.

Technology companies failing to step up active outreach and engagement to offer internships, engineering scholarships, and financial aid/incentives for disadvantaged or underserved STEM-oriented students.

Although STEM fields are male dominated, failing to recognize that the reasons for the STEM gaps supersede the issue of gender bias and encompass socioeconomic or sociocultural factors.

Failing to democratize STEM by not mitigating unfair practices and coercion in favor of one demographic over another and regardless of gender or socioeconomic or sociocultural status.

Not exploiting STEM as a tool to “remedy” ill-posed political messaging as certain messages and/or its delivery could disservice or disenfranchise certain social groups.

Lack of policy reforms to restructure STEM education before true change can occur and benefits realized.

It is more likely that STEM-disposed students will blend both STEM and certain non-STEM fields as part of a career pursuit strategy. Family members, caregivers, peers, and other outside influencers such as teachers and mentors can help curate STEM affinity and bridge STEM and non-STEM interests. However, efforts to deliver an overpowering STEM message were often seen as an attempt at indoctrination that could curb freedom of choice and threaten self-interests, thus deterring students’ STEM pursuits. Some pointers that were recommended to assist in building STEM affinity and capacity and that could contribute to STEM career preparedness, included the following:

- STEM subject diversity aligned with students’ interests;
- Practical, real-world exposure and hands-on problem-solving experience;
- Participating in competitions and fostering competitive (risk-reward) spirit;
• More integrated, multidisciplinary (non-siloed, non-textbook-based) learning to better understand interdisciplinary connections;

• More STEM with arts project-based learning and team building; and

• Exposing students to STEM at a young age and assuring continuity in STEM learning programs from elementary school through high school.

Also, the students expressed a desire to learn how to face challenges and embrace failures to develop confidence as part of the STEM character building process. The importance of nurturing inclusivity to mitigate gender bias in STEM emerged as did making the STEM learning experience more enjoyable by eliminating state testing and scripted programs. One’s prior STEM experience was also likely to influence persistence. It was found that a less-siloed STEM pedagogical structure in the middle school grades improved the continunity in STEM learning and stimulated engagement at the upper high school level. It also enhanced the students’ awareness of college and vocational/trade career pathways. STEM outcomes were highly dependent on early STEM exposure to diverse offerings aligned with students’ interests and maintaining continuity across the grades to incrementally build on prior experiences. Called for though was a more balanced approach to college/professional and vocational/trade career guidance. Peer influence was another important factor in one’s decision to pursue a STEM career pathway.

Positive teacher motivation and experiences together with curating a nurturing learning environment helped to enhance STEM engagement. Exposure to real-world team settings, internships, and tours of engineering and technology companies aided in understanding multidisciplinary synergies and integrated product team mindsets. ESM
High School’s diverse STEM offerings, electives, and clubs and the opportunity to participate in nontraditional STEM classes sparked interest and created opportunities for growth. Overall, ESM’s Spartan Academy STEM Program had positively influenced STEM pursuits after high school, but it was important to dispel the pervasive myth that STEM was strictly a college/professional-level pursuit.

Exploiting creative processes and environments in STEM pedagogy was considered paramount in stimulating engagement, as opposed to employing textbook-based, formulaic practices. Creativity enabled future thinking and elicited enjoyment that enhanced the STEM experience. The creative process can inherently exploit the synergies across a diversity of subjects and concepts that could help inform decisions regarding college or career pathways. Novelty, fun, and personal gratification were additional emergent themes. Creative environments and processes using non-STEM content generally did not dilute STEM learning or divert STEM interests, nor did it necessarily draw one closer to non-STEM fields, although such outcomes are possible.

Indeed, introducing creative aspects and non-STEM content into STEM learning was believed to benefit STEM engagement. ESM High School’s STEM offerings and diversity in electives were found to positively influence students’ college/career decisions. Several other benefits and best practices were identified namely, (a) the freedom to engage in out-of-the-box brainstorming and experimentation (creative problem solving), (b) exploiting STEM and non-STEM synergies for innovative and purposeful (humanitarian) outcomes, and (c) a sense of personal achievement in applying creative and customized solutions to address real-world needs.
The decision to replace siloed learning with an integrated STEM learning model was unanimous. The concepts of STEAM and STREAM (the “R” for “Research”) learning were introduced early on during the focus group discussions; these concepts were believed to make STEM learning less rigid and formulaic and more purposeful. The idea of multidisciplinary, integrated, and practical STEM problem solving in a group setting was eagerly embraced. ESM High School has demonstrated partial strategies for integrating the STEM subjects including certain non-STEM content, but its efforts should be expanded and the steps towards STEM program reform rigorously explored.

The successful outcome of an integrated STEM program or curriculum was considered highly teacher dependent, where some teachers were in a better position than others to effectively relate the subject domains and the varied content. The teachers who taught multiple STEM subjects had a greater capacity for appreciating the underlying connections. ESM High School’s support of integrated STEM learning opportunities kept the students engaged and helped in their college/career decisions, and that this type of learning should expand sooner than later.

As previously stated, STEM plus the fine arts or STEAM, was considered an enabler for STEM engagement/persistence. The rigid STEM-only education and workforce agenda was found to be outdated and potentially misleading. The natural relationships and connections between STEM and the fine arts facilitated the emergence of self-expression, creativity, and innovation; however, a best-case strategy for achieving a connective STEAM fabric was deemed challenging due to the state standards governing the curriculum hence, the plan forward was uncertain. ESM High School had already started on a successful path; however, its efforts to bridge disciplines and programs
required further development. The inclusion of the fine arts into the STEM curriculum was deemed beneficial to STEM learning and engagement, but a certain degree of skepticism prevailed regarding the implementation of an effective near-term strategy and the long-term outlook.

A potential fine arts inclusion strategy specifically explored the math-music connection and its effect on multidisciplinary STEM engagement/persistence. However, the findings were inconclusive. There was no clear or obvious “entry point” for music as a STEM engagement enabler and no apparent evidence to suggest that music had any measurable impact on STEM engagement. Music, as an enabler for increasing STEM interest, depended on one’s interest or passion in the domain of music that encompasses theory, composition, music production and sound fidelity, novel instrument design, and so forth. Some of these areas can inspire STEM interest especially if music is combined with technology, math, software, and art.

Notwithstanding, music could help one face the rigors of STEM by providing an “offramp” to understand and appreciate the inherent scientific contexts and mathematical structures. Frames of thought could be expanded to overcome the perceived disconnections between STEM and the fine arts through music. Music represents an acoustic modality for learning, communicating, and for personal enjoyment. Other learning modalities can be highly effective for STEM learning and engagement.

Overwhelmingly, visual and tactile learning were cited as the most effective modalities. Whereas visual and tactile experiences were naturally preferred modes, learning through auditory stimulation or contexts was considered less effective, excluding of course verbal lessons, communications, reading, and listening exercises. The nature of
a project may depend on sound as an observable or a measurable feature, but again, there was no clear indication of music as a STEM enabler. A detailed discussion of the synthesized findings across all the focus groups aligned with the research questions and the overall conclusions of the study are provided in the next section.

**Synthesized findings and overall conclusions on the STEM gap.** A synthesis of the findings identified in the study across all the focus groups and aligned with the research questions was shown in Table 4.4. The contributing factors to the STEM gap were subdivided along each research question. Table 4.4 presented a clear and concise picture of the STEM gap issue in the context of the ESM High School Spartan Academy STEM Program. Certain findings and conclusions were expressed in a more general way and are identified as such when possible; however, none of the findings and conclusions were generalized or applied to any other research context.

In the final analysis, the conclusions on the STEM gap problem were realigned along six main themes based on the findings organized by the research questions as follows: STEM affinity, institutional STEM curriculum, STEM learning environments and strategies, STEM marketing and messaging, organizational and individual factors, and social justice detractors. The realignment into the six themes facilitated the development of implications and recommendations that will be discussed in Chapter 5. The STEM gap factors for each research questions are discussed next beginning with the RQ1 associated factors.

**RQ1 STEM gap factors.** Recall that organizational incapacity to build and nurture STEM engagement for those with high STEM affinity was elemental to the STEM gap problem. Across the groupings shown in Table 4.4, various barriers to STEM
engagement emerged that contributed to the STEM gap and were recurrent themes throughout the study. The factors cited below were situational to ESM High School but in some cases were described in a generic way but not generalized to other research contexts. The barriers to STEM engagement were identified including mitigation strategies when possible.

To begin, STEM pedagogy and outreach were overly preoccupied with blindly recruiting “everyone” as a potential STEM candidate while losing focus on nurturing students with existing high STEM affinity consistently and non-forcefully. The STEM outreach and marketing was unprepared to appeal to students with low STEM affinity because programs lacked multidisciplinary diversity that matched students’ interests. Furthermore, the STEM outreach tact often emphasized college STEM careers while downplaying non-STEM and vocational/trade careers which limited students’ choices. The students did not want to be confined by the traditional definition of a STEM career. The failure to reframe STEM careers in both college/professional and vocational/trade contexts was a significant contributor to the gap.

“Systemic” organizational inertia delayed implementing near-term strategies for STEM curriculum reform. Organizational gaps were exacerbated by failing to build on early STEM exposure with diverse offerings that matched student interests. Motivational teachers along with nurturing learning environments and exposure to real-world team settings, internships, and tours of engineering/technology companies played important roles in STEM engagement. Creative and hands-on problem-solving focused on realistic problems that helped to inform college/career decisions. Additionally, peer influences affected decisions to pursue a college/professional or a trade/vocational career pathway.
Several factors that *force-multiplied* STEM disengagement sidetracked STEM learning capacities. The factors included: outdated STEM-only learning practices based on rigid, formulaic, and siloed curricula; the lack of multidisciplinary, integrated (STEM and non-STEM), and practical problem-solving activities in group settings; and the lack of instructors able to teach multiple STEM subjects and articulate the underlying connections across the disciplines. Failing to exploit visual and tactile (hands-on) learning modalities to show interdisciplinary connections was a significant drawback. Traditional or nonprogressive STEM curricula failed to exploit the natural relationships between STEM and the fine arts limiting self-expression, creativity, and innovation. Not exploiting the fine arts in STEM further limited an understanding of the inherent synergies between scientific context, mathematical structure, and artistic content.

ESM High School’s diverse STEM offerings, electives, and clubs along with the opportunity to participate in nontraditional STEM classes, albeit in a limited capacity, sparked interest and growth opportunities in related fields. The school’s support of integrated STEM learning when feasible kept the students engaged and informed their college/career decisions. However, the school’s efforts to bridge disciplines and programs required further development. The inclusion of the fine arts into the STEM curriculum was deemed beneficial to STEM engagement but again, was limited. The STEM gap factors associated with RQ2 are discussed in the next section.

**RQ2 STEM gap factors.** Foremost was the failure of current STEM outreach programs to focus on students with high STEM affinity including those academically borderline in STEM (note: the students focused only on high STEM affinity whereas the educators identified both borderline and high STEM affinity). The focus on STEM-
disposed students who are academically borderline was in the vein of helping them “cross” into the STEM camp. The STEM gap had been exacerbated by failing to employ a multiprong strategy that fundamentally built on culturing STEM affinity and implemented a forward-thinking STEM pedagogical model. Respecting students’ rights to choose in accordance with their personal interests and beliefs was also important rather than having STEM foisted on them at the exclusion of all else and discouraging their interests.

ESM High School had rolled out an integrated, multidisciplinary STEAM program using project-based learning (PBL) protocols that stressed hands-on activities, but the program was limited. Meeting the requirement of the state standards and the teachers’ ability to implement new, novel STEM strategies revealed gaps. The ESM High School students demonstrated a capacity to embrace non-STEM subject matter in STEM class projects. However, music as an art form was not explicitly identified as part of the creative tool set for any aspect of STEM learning or engagement.

However, STEM programs continued to embody a legacy of siloed learning again burdened by the state education constraints. Breaking down the legacy silos amidst the constraints imposed by NYSED and the institutional mindset centered on teacher accountability and regional assessments was deemed challenging. The belief was that the standards competency-based pedagogy methods should be replaced by application- and outcome-based models to narrow the STEM gap.

Ensuring continuity in STEM learning and understanding multidisciplinary synergies (thematic threading), setting realistic goals, encouraging experimentation and risk-taking, and empowerment by managing failure were important in precluding STEM
disengagement. The lack of full spectrum synergies within and between STEM and other subjects, not showing meaningful multidisciplinary connections, and failing to explain the interdisciplinary nature across subjects via concrete examples or practical problem sets contributed to the gap.

Again, the slow progress in pivoting towards a STEAM fabric via an integrative, multidisciplinary pedagogical approach was felt to contribute to disengagement. In the STEAM fabric, the arts and humanities are fused into STEM, and includes the integration of English, arts, and the humanities for developing the necessary soft skills, combined with a content driving curiosity pedagogical approach. ESM High School had successfully infused selected aspects of the fine arts into STEM on a case-by-case basis. However, an artificial or forced intersection of the two domains was deemed potentially detrimental to STEM engagement because it could “dilute” STEM’s impact.

Novel interventions that stimulated creative independent/team learning, critical thinking, and knowledge discovery as part of a progressive STEM agenda was thought to increase engagement and narrow the gap. A progressive curriculum for example, would apply the fine arts like theatre, role playing, and improvisation. The fine arts were effective tools in science communications, embracing multiple perspectives and comprehending diverse frames of thought, self-expression, confidence-building, and in providing for rich contexts.

An inconsistency in the way the NYSED standards were applied across the grades led to discontinuous STEM learning cycles. The teachers were often forced to limit or drop the rollout of progressive STEM programs because of the state testing standards. The state education system perpetuated a siloed STEM learning mindset yet pointed to
the need for a progressive curriculum and creative lesson planning. The recurring
suggestion by educators and students alike was to eliminate regional testing altogether.

The scripted state tests were considered outdated and an impediment to true
learning. A combination of the ongoing pressures of state testing, using test scores as the
key performance measure, teacher assessments, and a resistance to progressive reforms
created stresses for students and teachers alike. Coping with the stresses led to burnout,
apathy, disengagement, shutdown, and withdrawal. Without significant reforms, the rate
of teacher attrition will increase, and the students will lose out on valuable academic and
career opportunities. The inability to reform current processes was a disservice to
students and a personal deterrent to STEM engagement. Adopting progressive reforms
achieved a better balance in STEM engagement in the near term and prepared the way for
incremental improvements over time. Teachers’ subject-class territorial mindsets
coupled with a fear of change was also part of the challenge.

The ESM High School teachers had some latitude in introducing creative ways of
teaching STEM subjects within reasonable and practical limits. On the other hand, the
school had to be cautious of rolling out programs that could be deemed too risky or out of
scope to avoid jeopardizing STEM grant funding. The teachers who wished to develop
or acquire new skills to expand their knowledge in multiple subjects often faced
challenges and had to consider alternatives that included recruiting specialists and outside
experts; and developing a common planning tool to allow for interdepartmental and
interdisciplinary STEM pedagogy. Limited school budgets and resources created barriers
that made it difficult to roll out new initiatives to shape the future of the STEM
pedagogical landscape at ESM High School. Additional challenges were faced in
teaching STEM classes with students across a spectrum of learning-disabled, behavioral, and other categories.

STEM was ill-defined in the absence of cross-disciplinary associations which called into question the effectiveness of today’s outreach strategies on long-term engagement. Applying a “one size fits all” or monolithic approach to STEM pedagogy that lacked flexibility in customizing programs to meet students’ needs and interest areas was highly problematic to STEM engagement. The longer it took to expand STEM programs, the more the students were shortchanged, and the greater the STEM attrition rate.

Gaps were uncovered in integrating math across various disciplines. Effective connections were not being made between math and the fine arts like music. Cross-disciplinary coordination and support often failed to bridge disparate domains to expand frames of thought and create new opportunities to fill the gap. Limitations in PBL protocols that helped students acquire the necessary soft skills and integrate them in STEM learning environments and activities further added to the gap. Failing to utilize multimodal content delivery was highly impactful to STEM learning and engagement, meaning a combination of visual, tactile (hands-on), experiential, and auditory learning applied to real-world problem-solving sets.

STEM learning that failed to tap into optimal group/team collaboration and group size dynamics guided by teacher mentorship was another concern. Group engagement, where larger group sizes were preferred over smaller groups, and where teachers experienced difficulties with group dynamics, was also problematic to STEM
engagement. Team/group collaborations were generally considered unfeasible, awkward, and unable to produce the desired outcomes.

Small groups were especially problematic and produced less-desirable outcomes than did larger groups revealing soft skills gaps, particularly interpersonal communications skills, exacerbated by the overuse of social media platforms. The failure to expose students to real-world problem-solving activities inside and outside the classroom was another contributor to the STEM gap. For example, failing to connect the STEM programs to industries and workplaces and not increasing the number of internships, corporate scholarships, and college credits all served to exacerbate the problem.

Marketing, advertising, and outreach were also problematic to STEM engagement. The messaging favored promoting college/professional STEM paths while downplaying vocational/trade career paths which disenfranchised some groups. The STEM outward messaging was often confusing and conflicted, and the goals of recruitment lacking vis-a-vis workforce preparedness. The over-propagandization of STEM was risky and could backfire adding to attrition. Failing to improve the structuring, marketing, and implementation of progressive STEM curricula was thought to derail higher education and career STEM pursuits. Nonoptimal communications and marketing of STEM offerings coupled with too wide of an array of options often confused and overwhelmed the students.

Another significant contributor to STEM disengagement was a deficiency in school career counseling that had fallen on the shoulders of the educators. School counselors were unprepared to dispense informed guidance regarding college,
Of major concern was the failure to provide sound and consistent career guidance, enable informed career decisions, and encourage individual passions. The counseling failed at times to respect the student’s right to freely choose a vocational/trade career path over a college/professional career path based on their interests. The failure of counselors to give informed, dependable guidance and not recalibrating the notion of STEM as inclusive of technical vocational/trade jobs added to the gap problem. As a result, those interested in STEM vocational trades felt disenfranchised from mainstream STEM opportunities.

Career counseling often overlooked cultural values in weighing salary and self-interests against other variables that included: risk versus reward, job market, expectations and demands, managing stress, and dealing with negative outcomes especially for those of low STEM affinity. A complementary engagement strategy was to exploit self-motivational theories to stimulate one’s creative potential and look beyond salary and pure self-interests. Additionally, the teachers and counselors must develop effective soft skills as a component of the STEM pedagogical strategy to provide sound academic and career guidance to students in a confident and reliable way.

The ability to share the STEM vision and articulate the possibilities, options, and opportunities to students and their parents or mentors depended on informed counseling. A lack of clear communications, counseling, and coordination at strategic points in a student’s career further contributed to disengagement. Enabling students to make their own academic and professional career choices while building on their interests and weighing career trajectory factors was at the heart of informed counseling. The school successfully coordinated with parents, guardians, caregivers, and families to inform them
of STEM options for 2- or 4-year colleges, vocational trades, scholarships, internships, job markets and timelines, and the associated risks/benefits.

Less obvious however, is that the STEM gap is exacerbated by failing to teach students how to confront real-world challenges and make informed decisions, and not cultivating a resilience mindset to train them in strategies to embrace and recover from failure. Specifically, the gap widens by failing to (a) raise awareness of the possibilities regarding STEM, (b) empower independent choice, (c) encourage an entrepreneurial risk mindset, (d) inspire a culture of curiosity and the practice of inquiry, and (e) cultivate an institutional growth mindset. Myriad other factors were identified that have further widened the STEM gap.

For instance, all access to technology virtually anytime and anyplace had reinforced the notion of instant gratification and the difficulties of managing failure or expectations that come along with it. Also, preoccupying oneself with the distractions of technology in the classroom reduced attention span and learning capacity. Promulgating the populist notion of STEM as an elitist pursuit was another factor in widening the gap as was perpetuating myths regarding the rigors and demands of STEM fields compared to non-STEM fields. Failing to recruit industry experts to provide practical STEM education and training experience to inspire and motivate students worked against the goals of STEM engagement as was failing to foster an integrated product team mindset early on for team building purposes.

Next, high demands and expectations were placed on ESM High School by higher education to consistently produce “master class” STEM scholars. The high school was obligated to do all it could to abide by the rigors of meeting the state testing standards
and did its best to transfer knowledge and teach basic skills to its students to the extent practical. Master class achievements, however, should be on the shoulders of higher education, although the high school should deliver reliable college preparatory instruction.

ESM High School set itself apart from other CNY schools by having the core of a progressive STEM program that integrated art electives on a case-by-case basis. The program sought cross-disciplinary connections, promoted critical-thinking and problem-solving within real-world contexts, and supported career and technical education classes that had become a model for other CNY schools. The school’s STEM curriculum had been encumbered by state education standards and policies that contributed to the STEM gap. The STEM gap factors associated with RQ3 are discussed in the following section.

*RQ3 STEM gap factors.* Recall that research question RQ3 examined the root causes of STEM attrition. For instance, the shortcomings in STEM program diversity and the failure to deliver an integrated, multidisciplinary curriculum were at the top of the list, followed by the lack of (a) positive educator leadership, (b) motivational teaching styles, and (c) curating a nurturing environment. Gaps continue to exist between STEM and the arts and humanities. Failing to make interdisciplinary connections and “stretch” the curriculum had a detrimental effect on STEM engagement. The constraints of the state-mandated curriculum hampered the STEM teachers’ ability to deliver fundamental lessons that exploited interdisciplinary connections.

Maintaining the status quo in STEM educational practices was believed to only exacerbate the disparities in STEM outcomes and widen the gap. The ESM High School STEM teachers from different disciplines had a common goal of working together to
design their own content modules and be entrusted to deliver them when schedules permit amidst the constraints of a rigid curriculum. The curriculum created barriers for the teachers to deliver novel products that could ultimately supersede the state testing standards and scripted programs. Again, the thrust remained a challenge due to that lack of adoption at the state level.

Non-impactful STEM programs were felt to disillusion and disengage students. Engaging teachers played a crucial role in inspiring and motivating students and avoiding complacent teaching styles or delivering content in a non-stimulating way. Similarly, student complacency and apathy were the outcomes of failing to consistently deliver a focused and flexible STEM program with options or electives and by limiting students’ choices by being indifferent to their interests. Youth should be exposed to STEM but not be pressured into it, and students should be enabled to make their own choices—a viewpoint thought to make the difference in achieving true and persistent STEM engagement.

Students who retreated and migrated towards self-interests or pursuits they felt were beneficial to them did so without considering the larger picture. The students who disengaged from STEM may have convince themselves that overachieving for college was unnecessary. They were less incentivized to hone their skills and were content just achieving a passing GPA. In fact, failing to cultivate “unicorns” as embodiments of the intersection between the science/technology and art/design domains also contributed to the gap. People are naturally more STEAM creatures than they are STEM creatures. It behooves schools to make such connections and resonate with various aspects of education, personal achievement, human nature, and so forth.
Where opportunities arose for the STEM teachers to trial a novel STEM or STEAM pilot program, it was often short-lived, temporary, or sporadic. The result was an ongoing “stop and go” series of pilot programs that were never guaranteed to continue for a variety of reasons. An over-paced series of trials or pilot programs resulted in “STEM information overload” and was considered a detriment to STEM engagement. The “disjointedness” of programs over time led to a confusing and bloated STEM education landscape, loss of focus, unachieved goals, and eventual teacher burnout and student disengagement all contributing to the STEM gap.

Another contributor to the STEM gap centered on the theme of “no child left behind.” Students were taught to “trust the process.” They were expected to do what they were told, “regurgitate” the curriculum, avoid experimentation and risk, and conform to a culture of achievement defined by the state education standards built on a Regents testing/grading system. A constrained educational curriculum was considered counter to a progressive STEM or STEAM learning model rollout. Although the teachers were obliged to prioritize their efforts towards preparing the students for the state Regents tests, they felt strongly about the need to reform the curriculum as it stood. State leaders, institutions, and policy makers were failing to act however, to eliminate a “one size fits all” (monolithic) STEM pedagogical model.

Nonetheless, the teachers were pushing for education that was unshackled from the burdens of the standardized tests. Standardized testing was deemed a barrier to true education. Being consumed by the fear of passing the tests was not only psychologically stressful and unhealthy for students but negatively impacted their decision to pursue a STEM field in college. However, STEM curriculum reform cannot be on the teachers’
shoulders alone. It required the cooperation of the district and state education agencies. The teachers and the school district expressed concern by the lag of state education leaders to take more aggressive steps at changing a rigid system to prevent STEM erosion.

Next, the lack of collaborative group activities that allowed for independent or individual study time with exposure to practical problem-solving and real-world workplace settings was a significant factor. Opportunities for practical, real-world projects and adapting to a college-level mindset that emphasized applied learning was deemed important. The lack of access to corporate facilities or natural laboratory settings to expand the students’ experiences detracted from STEM capture. Neglecting to introduce practical, hands-on activities and creating “artificial” disciplinary connections that did not naturally fit together worked against engagement and narrowing the gap.

Failing to show the mathematical connections across multidisciplinary subject domains and in the context of real-world applications was another concern. Understanding the link between math anxiety and STEM engagement was of paramount importance. Not imparting and acquiring the knowledge, skills, and confidence in math added to STEM disengagement. A less than student-friendly curriculum combined with a fear of failing the state Regents tests exacerbated math anxiety. The gap grows when teachers fail to intervene to help students overcome negative attitudes about math or do not take steps to empower and engage them, undo their worries, build self-confidence and self-belief, and encourage them to keep trying. Coping with failure was central to the math anxiety issue. Again, restrictive state education standards that constrained the STEM curriculum compounded the problem.
Another factor contributed to math anxiety and widening the STEM gap. The high school teachers were faced with undoing a legacy of intrinsic anxiety seeded during the elementary/middle school years aimed at assuring that younger students “get the math.” Many of the middle high school students entering high school arrived with an intrinsic apprehension of math and erected walls that limited their capacity to learn, advance, and succeed in STEM. The incoming anxiety over math naturally created a challenge for the high school STEM teachers who believed the students had the capacity to be successful, but where they were less self-driven because of their fears.

The lack of elementary/middle school staff training to help teachers and younger students embrace math, manage failure, build confidence, and learn persistence through a different lens increased the pressure on the high school teachers. Further, failing to moderate students’ dependence on tools and electronic aids to accomplish basic mathematical tasks and conquer instant gratification had contributed to the gap because fundamental math skills were apparently lacking. Instant gratification combined with a culture of state testing standards, scripted programs, and institutional grading criteria conspired to widen the STEM gap. Emphasizing the abstract nature of math was another STEM gap factor for some individuals; steps should be taken to show math’s relevance to real-world applications that taught students practical life skills.

Again, the lack of informed school counseling on STEM field opportunities was identified as a major concern. On the other hand, a close-minded attitude against accepting informed STEM career guidance from teachers, for example, contributed to the gap because important and timely opportunities may have been ignored. In either case, enabling informed choice in navigating the “unknown” rather than imposing the standard
message about STEM was of paramount importance. Indeed, as was previously stated, continuously drilling the traditional STEM message rather than nurturing STEM engagement beginning at a young age and enabling informed, free choice was detrimental to STEM engagement and served only to widen the gap. The freedom to choose, as part of a strategy to narrow the STEM gap, helped in shaping one’s confidence to make informed decisions about a STEM career.

The gap widens when STEM character building fails to teach students to embrace challenges and how to overcome setbacks to instill self-efficacy, self-realization, self-attitude, self-confidence, and increased self-awareness. Again, the source of the gap traced back to a bloated testing culture driven by the state education standards coupled with school counselors who were uninformed or unprepared to dispense effective guidance about the realities of STEM higher education and careers. However, STEM marketing, advertising, and outreach played a major role in the overall scheme.

The gap widened because of the ineffective marketing and advertising of STEM offerings and the inconsistent outreach strategies before and during high school. For example, STEM engagement and nurturing strategies had first been used to capture students at a young age in elementary or middle school; once engaged and upon entering high school, the students faced a much different STEM culture due to the inconsistencies in the way state, district, and high school policies were applied in support of STEM programs. The diverse STEAM programs of elementary/middle school versus the more siloed STEM programs of high school specifically illustrated the disparity.

The nonuniform outreach and engagement strategies disrupted the continuity of STEM programs before and during high school and contributed to STEM attrition.
Furthermore, a misguided STEM marketing campaign and inward messaging fostered misconceptions that set STEM students up for failure as they enter college. High school students are a vulnerable group—they may be unsure of their college/career path while encouraged or perhaps pressured to pursue STEM and where non-STEM pursuits were often frowned upon, yet their path forward may be uncertain or misguided.

Next, the federal government had “hyped” STEM to the point of creating a sense of urgency, real or not; nonetheless, the message lacked substance by not defining what STEM education truly meant and how to develop and implement STEM programs for high visibility and impact. The messaging was vague and open to interpretation, leading to a wide array of programs that on one hand, can be beneficial in terms of their diversity, but on the other hand, confusing and inconsistent with varied expected outcomes. The problem was also one of where or what to invest in when it comes to STEM. Whereas many good ideas have been conceived that have yet to be adopted for “mainstream” implementation, it was important to pick the right programs with a high return on investment, implement them consistently, and allow time for the gap to close.

Deciding to pursue a STEM path yet barraged by messages like “STEM is hard” or “grades are key,” can lead to dubious outcomes. The conflicted messaging and resultant misconceptions about STEM as reserved for the elite, or that some majors are harder than others, may “flip the switch” culminating in STEM disengagement between high school graduation and the first year of college. STEM should not be advertised as something that only those with the “right credentials” should aspire to. STEM is simply not suited for everyone. The concern reached back to school counselors and the failure to dispense authentic, informed guidance to students about STEM opportunities to enable
autonomous choices tempered by expert guidance despite the marketing and messaging that abounds.

The lack of a consistent, robust STEM outreach campaign and academic support system that targets its students and outside industries or institutions derails the mechanism for building sustainable STEM interest. Advertising myriad choices of non-STEM offerings and the conflicting class schedules limited STEM opportunities. The discontinuity “interrupts” the longitudinal continuity and flow of students’ STEM learning experiences since elementary and middle school, which was also believed to detract from sustainable STEM interest.

Furthermore, the gap worsens by failing to implement a coherent STEM marketing and outreach strategy inclusive of disadvantaged, underserved, or underrepresented groups. The strategy builds on aspirational pursuits and achievements, an anti-elitist agenda, and tearing down barriers due to socioeconomic and sociocultural stereotypes. An absence of positive family influences or support including peer encouragement can undo the strategy. The STEM gap widens if the needs of such groups are not addressed and if STEM marketing targets only certain demographic groups of interest.

The issue becomes one of *democratizing* STEM by expanding opportunities that match anyone’s specific interests in a STEM career, but that are not purely driven by salary or economic incentives. Self-efficacy, self-improvement, advancement, and positive social contributions are stressed instead. Multiple “systemic” issues and shortcomings at the federal legislative, state education, and district institutional levels pointed to the need for reprioritizing education for everyone regardless of privilege, class,
wealth, and power. Without taking more aggressive steps to address the systemic issues, the students will suffer, and the lack of action will continue to contribute to a greater societal concern—middle class erosion as a socioeconomic issue—further widening the STEM gap.

Family influence can play another role with selfish motives though. It can be used to urge students who may or may not be STEM-disposed to achieve good grades at any cost to qualify for college STEM scholarships to reduce personal financial burdens. The scheme may push the wrong candidates into the STEM pipeline contributing to attrition. On the other hand, high school STEM graduates who met the minimum state grading requirements and who were underprepared for the rigors of the college STEM experience, could face a rude awakening. Some non-STEM fields of study may offer a higher benefit-to-risk ratio in terms of competitive salaries and benefits, lower investment and scholastic intensity, and reduced stress; however, a broader set of considerations should be used to make informed career decisions. The demands of a college STEM major may “shock” students into switching to a non-STEM filed of study or cause them to drop out of college altogether. Rather than exploit financial gain, it is best to nurture STEM affinity in a self-honest way and for the right reasons.

Societal “norms” and expectations and family upbringing give rise to potential gap contributors that evoke stereotypical beliefs on the expected roles of males versus females in STEM careers. Barriers to STEM entry for females have persisted and are difficult to change. A variety of factors have contributed to the problem ranging from negative family and peer influences in pipelining females toward STEM knowing it is male dominated and highly competitive, not exposing females at a young age to STEM
content, to the failure of academic marketing and outreach to empower females to make their own choices in STEM. Exposing females to STEM at a young age was considered important in establishing a foundation to build upon in their later years. A detrimental approach was to not support females’ decisions to split off into STEM and/or non-STEM classes and not customizing the STEM program to appeal to specific interests. Attempting to force females into STEM despite being less inclined to do so or not at all was viewed as a strategy that often backfires, thus contributing to the gap.

Related to the earlier issue of STEM marketing and messaging was the concern that the STEM movement may be generating a myth on the need for females in STEM. The persistent “STEM for girls” message has had a polarizing effect on STEM attitudes and had aggravated the problem. Again, the pressure on females to engage in STEM can backfire in that it can discourage them from naturally and freely choosing fields or professions that they wanted to pursue. Choosing a STEM field should be about an individual’s passion, talent, fit, and choice. It should also be about moving past the stereotypes and not being driven to fill an “artificial” quota based on a constant barrage of marketing on that front. Perpetuating the gender bias stereotype and failing to nurture opportunities or cultivating self-efficacy on behalf of STEM pursuits has helped widen the gap. The teachers explicitly fostered associations between strength and empowerment and being a female in STEM. However, more work was needed to engage females in STEM by breaking down the gender-bias stereotypes and through thoughtful marketing campaigns.

Another gap contributor in female STEM engagement dealt with the tact used by teachers, referring to female empowerment in choosing what they want to do, become, or
pursue. Instead of questioning or challenging their choices, a better approach was to nurture, guide, and expose them to opportunities and options to help them make informed decisions in pursuing STEM or any other field of interest. A social injustice arises, and doubt is cast when females are questioned about their STEM choices.

Federal legislation that required technology companies to hire a certain percentage of individuals to meet quotas across, gender, race/ethnicity, or other socioeconomic and sociocultural criteria could indirectly add to STEM disengagement. The quota system has resulted in the hiring of unqualified or misplaced candidates that led to “workforce tension,” rather than hiring based on talent and capability regardless of quotas. Workforce tension here referred to an imbalance in workforce supply and demand of certain types of skilled labor and positions that could be difficult to find and fill, thus potentially adding to the STEM pipeline gap. The quota system, although well-intended, sets itself up for failure because it neglected the science and the labor force data to launch a truly informed, equal opportunity hiring campaign.

In addition to gender-bias, socioeconomic factors should be more closely examined in filling the STEM gap. The relevant socioeconomic issues and relevant contributing factors were tied to federal and state legislation. Failure to recognize that the socioeconomics outweigh the gender-bias issue in terms of a greater number of class and race issue that such groups continue to face helps to widen the gap. The STEM gap factors associated with RQ4 are discussed in the next section.

*RQ4 STEM gap factors.* The research question RQ4 focused on the gaps that worked to erode the number of STEM majors or STEM career launches after high school graduation. Recall that a significant contributor to the STEM gap was the changing role
of the ESM High School counselors regarding career guidance for the students. School counselors had traditionally played a pivotal role in guiding a student’s career path, but that responsibility has significantly shifted more to the teachers—a finding that was corroborated by both the student and educator focus groups. The school counselor’s role had become more about handling social-emotional and behavior issues. Informed career guidance had become less of a priority to school counselors, thus adding to the STEM gap.

Furthermore, the teachers were not trained or necessarily well prepared to dispense informed guidance. Then there was the issue of students who were not receiving any informed, reliable form of counseling support directly from the educators or from other sources. The combined lack of informed, engaged career counselors and the absence of reliable, consistent, and informed STEM career guidance for students was a significant contributor to the STEM gap. Indeed, the myriad electives, lack of direction given to teachers, sporadic coordination between administration and teachers, and the resultant distractions had exacerbated the situation to the point where guidance was incomplete, uninformed, or disjointed. Assuring the continuity in STEM teacher/counselor/mentor support systems stood out as a major concern in the strategy to ensure informed guidance and in narrowing the gap.

School leadership, administration, and STEM teachers were generally aware of the need to make improvements in the current STEM education policies, procedures, and best practices that would help improve STEM engagement upon graduation. Additionally, it was generally accepted that a siloed, in-class, theory-based learning environment was inviable and was frowned upon by both students and teachers. The
teachers were fully aware of the disconnection among the STEM subjects and between the STEM and non-STEM subjects that perpetuated siloed learning. The STEM students who were largely exposed to a siloed learning environment were more likely to experience a “rude awakening” by the time they entered college. A call for a shift in educational approach would further break down the legacy silos and contribute to narrowing the gap.

Without a substantial shift in educational approach, engagement issues and gaps will continue to persist or worsen. The need was expressed for STEM curriculum reform at the state and district levels. The STEM gap can be filled by implementing, monitoring, and refining a well-crafted, practical, and sincere plan for full impact and measure instead of a superficial one that barely moves the needle on progress. A beneficial approach was to engage core teachers across STEM, history, and languages and strive to affect change through improved multidisciplinary education coupled with informed career counseling. The strategy reinforced the arguments for eliminating the state Regents exams altogether to mitigate the STEM gap.

A step in that direction calls for curriculum reform in support of delivering integrated, multidisciplinary STEM content. STEM and the humanities should be formally integrated and taught together under the curriculum focusing on meaningful and purposeful connections and practical contexts. The teachers across multiple disciplines should find ways of collaborating more closely and effectively to achieve that goal. All the disciplines and teachers should be better coordinated, orchestrated, and “integrated” with STEM and to work together for the benefit of student engagement. Teaching about the connections across disciplines along with explanations and examples was an
important goal and a necessary next step. Also, a tighter connection was needed between math education and other disciplines and vocational trade classes. The concept of STEAM as an integrated, multidisciplinary STEM-based approach that draws on non-STEM subjects, needed to be fortified and clarified.

Next, the teachers understood the need to quench the students’ thirst for knowledge and unleash them to apply that knowledge to solve real problems; indeed, balancing the theory and research against practical experience and applied theory was part of the plan to narrow the STEM gap. For instance, outside-class or cocurricular activities including clubs were clearly preferred over a traditional STEM classroom setting because they were less formal, unstructured, nonhierarchical, and non-imposing. The students and teachers were better able to connect, interact, and communicate with each other, thus building relationships that effectively translated to the classroom. The students were more able to explore, ask questions, and express their interests.

The key outcomes were success in building relationships and expanding awareness of multidisciplinary connections in a natural context that ultimately benefitted the classroom environment. Such experiences better enabled career decisions through enhanced awareness. The importance of having an environment for autonomy or the freedom to learn emerged coupled with internships that built confidence through natural and practical learning. Facilitating opportunities for learning outside of the traditional classroom along with arranging internships at technology-based businesses allowed for up front and close exposure to the various facets of STEM “in action, in the field.”

The failure to undo inefficient student group/collaborative processes that were deemed unproductive served to widen the gap. The teachers and students who were
unable to effectively share ideas and hold brainstorming sessions in a group setting failed to acquire the technical and soft skills important in professional career settings. From an in-classroom perspective, what was found to work was a project/goal-based learning model using a facilitator tier to assist the students across multiple projects and giving the students “ownership” of their individual projects, or more exactly, about the students being engaged and invested in their project outcomes. The model included independent, discretionary time complemented by group collaboration with a balanced mix of participants to convert the “individual” mindset into a “group dynamic” mindset that encompassed multiple perspectives. Student “buy-in” was key in assuring a plan was in effect to achieve a successful outcome.

The students should be challenged to (a) independently find solutions and witness the outcome of applying their problem-solving skills, (b) expect some outcomes to be better and others, and (c) be prepared to manage failure. Assuming the students were serious and invested, the teachers and facilitators could provide a limited amount of guidance. The idea was to take the students outside of their comfort zone, engage them while instilling a level of confidence that they can achieve results regardless of the outcome, and keep them focused by eliminating unnecessary distractions. Placing them in a less rigid environment outside the classroom facilitated the above learning approach.

Small groups were effective when the students were taught how to interact, be open-minded, and risk discourse. Unfortunately, many students did not comprehend or thought they needed the soft (social) skills considered important for effective communication and group interaction, which were characteristic of industry integrated product team environments. Hence, experience with small group collaboration exercises
can provide valuable lessons in self-confidence and self-conduct in the context of STEM engagement that indirectly contributes to narrowing the gap.

Next, STEM marketing had not resonated well with many students which added to the disengagement. The recurrent themes that were poorly articulated or missing altogether in STEM marketing and outreach included gender parity, equity, equal opportunity for high-paying jobs, reward and fulfillment, financial security, and personal happiness. Indeed, other variables were found to collectively be more vital in STEM career decisions over salary and compensation or personal interests. In addition to financial benefits and aspirational goals, the variables included market demand or job availability; willingness to commit time and effort including financial investment; and a host of other tangible and nontangible factors. The STEM message should highlight career decisions that were not be based solely on salary or personal interests but that balanced multiple decision variables such as job demand, advancement opportunities, and so on.

Further contributing to the STEM gap on the marketing front was the lack of expanded outreach and advertising of STEM programs with a clear definition and consistent message to elementary and middle school grades. Such marketing involved presentations and visits by high school teachers and students to describe the STEM or STEAM and any specialized program offerings. Particularly, the students should actively promote the STEM program by talking about their experiences and knowledge gained, projects and successful accomplishments, the many fun group activities, learning opportunities, and friendships formed. Additionally, local technology companies should
step up active outreach and engagement to offer internships, engineering scholarships, and financial aid/incentives for disadvantaged or underserved STEM-oriented students.

Social justice considerations that affected the gap and were related to STEM marketing/outreach highlighted technology’s role in society for (a) improved quality of life, (b) opportunities and incentives for underserved groups, (c) philanthropy and humanitarian needs, (d) contributions to job growth and societal financial health, and (e) corporate or other organizational support that can lead to myriad opportunities. Additionally, females are an underserved, underrepresented demographic group in the STEM fields and were central to the social inequality issue. Females should continue to take a stand on the growing number of women entering the STEM fields emphasizing no limits in breaking through the “glass ceiling” as a response to the disparity issues.

Although STEM fields have been male-dominated, the gaps were not strictly or even largely due to gender-specific factors. Indeed, the reasons for the STEM gap go far beyond gender bias and it was important for the STEM messaging to reflect the larger socioeconomic and sociocultural barriers. The intent was to democratize STEM for everyone, to maintain a fair and level playing field, and to not force the STEM agenda in favor of one demographic over another. Individuals should be allowed to make their own choices regarding a field of study or career path, but certainly more can be done to show the opportunities and the paths forward to anyone regardless of gender or socioeconomic or sociocultural status to level the playing field.

It was true that some STEM fields were more competitive than others and combined with socioeconomic or sociocultural factors, created barriers to entry. On the other hand, STEM enabled pathways for competitive skills development in fields that
engendered social justice and social equality touchpoints. STEM and a support system for curating the desired skill sets would be at the heart of an expanding ecosystem of opportunities to serve affected social groups and to reduce the STEM gap. A side issue worth considering called on using STEM as a tool to “remedy” ill-posed political messaging. The message and/or its delivery could disservice or disenfranchise certain social groups.

Recall that another contributor to the STEM gap was the college institution itself which can intentionally or otherwise promote a populist image of *elitism* and a culture of *inequity* that can lead to disenfranchisement. Closer attention must be paid to the factors that failed to prepare students for college and that generally contributed to the gap. If unprepared for the college-level experience and the rigors of multidisciplinary group STEM learning, the students may become disillusioned and eventually switch majors or drop out of college. It was incumbent on higher education to proactively determine preemptive or corrective measures to ensure that STEM students were successful in the program or had viable alternatives. The lessons learned can be used to advise the high school institution(s) of the causes and effects at the secondary level that contributed to STEM disengagement.

ESM High School’s adult teacher professional focus potentially contributed to the gaps in STEM path continuity for students after high school. STEM engagement can suffer if the encouragement for students toward STEM is weak or sporadic. Finally, eliminating state standards testing and especially the state Regents exams should be seriously examined. The exams were viewed as detrimental to the STEM (STEAM) agenda and a disservice to students on a wide scale. Indeed, many policy reforms in
STEM education were needed before true change can take place and the benefits realized.
The next section examines several unanticipated findings of the study.

**Unanticipated Findings**

Several unexpected findings from the study and their association with STEM pedagogy and engagement are discussed as follows. The findings addressed (a) the changing role of school counselors, (b) misalignments between STEM recruiting strategies and STEM affinity, (c) non-STEM influences and the non-impact of music on STEM engagement, (d) ineffective small group collaboratives and STEM engagement, (e) barriers to integrating mathematics and other subject content, (f) non-STEM interests driving STEM attrition, and (g) the implications of artificial intelligence on STEM learning and engagement. The next section first addresses the changing role of school counselors and its effect on the STEM gap.

**The changing role of school counselors.** The lack of guidance and its effect on STEM engagement was a significant unanticipated finding. According to the students and teachers who participated in the study, the school counselor’s role had shifting from that of dispensing informed career guidance to one of being preoccupied daily with managing students’ social-emotional and behavioral issues. Informed career guidance had become secondary or altogether absent; instead, career guidance was routinely delivered by educators, but they were not necessarily equipped to provide thorough counseling regarding STEM careers. A lack of clear communications, counseling, and coordination at strategic points in a student’s career significantly contributed to the gap. The implication was that reliable and dependable STEM career counseling could not be guaranteed for students seeking guidance.
Also unexpected, the STEM career advice was largely slanted towards attaining a college degree and less aimed at technical vocational/trade certification. The students who were interested in STEM trades felt disenfranchised from what were viewed as mainstream STEM opportunities associated with higher education degrees and professional placements. The career advice seemed to be more of a “push” and less a freedom of choice and neglected weighing cultural values. The next section addresses unanticipated findings arising from ill-posed STEM recruitment and outreach strategies.

**Misalignments between STEM recruiting strategies and STEM affinity.**

STEM recruiting and outreach often uses a wide-angle or fisheye lens approach to gain as many followers as possible, regardless of their level of STEM affinity. This leads to attrition over time unless a well-posed strategy was implemented to progressively build on one’s innate interests. The study found that the level of STEM engagement was directly proportional to one’s STEM affinity and the nature of the STEM learning environment among other influences. Therefore, a myopic outreach strategy targeting those with moderate-to-high STEM affinity and STEM-disposed students who were academically borderline, was more effective—an unanticipated finding of the study drawn from the data analysis.

Effective STEM pedagogy must resonate with and build on existing STEM affinity and nurture that affinity in a consistent, non-coercive way instead of blindly and desperately recruiting non-STEM-disposed individuals—a go after anyone at all cost strategy. “STEM” was ill-defined and tried to appeal to everyone instead of focusing on those with high STEM affinity. STEM outreach and marketing were unprepared to
appeal to students with low or no STEM affinity. The focus on STEM-disposed students who were academically borderline was to help them “cross” into the STEM camp.

The STEM gap had been widened by failing to employ a multiprong strategy that fundamentally built on culturing STEM affinity and implemented a forward-thinking STEM pedagogical model. Respecting students’ rights to choose in accordance with their personal interests and beliefs was also important rather than having STEM foisted on them at the exclusion of all else and discouraging their interests. The next section examines the unexpected findings regarding non-STEM subject content on STEM engagement.

**Non-STEM influences revisited and the non-impact of music on STEM engagement.** The empirical, evidence-based studies in Chapter 2 showed that the introduction of non-STEM subjects into a progressive STEM curriculum provided for rich, impactful learning contexts. The present study sought to find a possible link between music and STEM engagement. However, the study showed that music was not explicitly identified as a STEM engagement device, which was another unanticipated finding. The data analysis could not find any direct link, and it was concluded that music did not play a vital role in STEM engagement at ESM High School. The finding and its implication contrasted with the perspectives of Daugherty (2013), Gordon et al. (2018), Grant and Patterson (2016), Hummell (2014), Moyer et al. (2018), Payton et al. (2017), Slater et al. (2017), Tobias (2014), Wu et al. (2015), and Wynn and Harris (2013) on the eclectic ways to engage with music through technology and math including performance art in the context of STEM learning. Music had not been rigorously tested or evaluated.
in any type of empirically based STEM interventional study, thus opening an avenue of possible future research.

The above findings bear a closer examination regarding the ways that music can become part of the STEM learning experience either as a stimulus for learning or as an intellectual exercise in linking the art of music to the science and mathematics of sound. Furthermore, the knowledge gained from brain learning studies can be used to inform scientists on ways to impart artificial intelligence (AI) algorithms in machine learning (ML) and robotics (Eagleman, 2015, pp. 186-190). For example, the Defense Advanced Research Projects Agency (DARPA) launched a project to infuse music-theory-based algorithms into machines to build a jazz-playing robot that was able to improvise with human musicians (Choi, 2015). Using the lens of STEAM via a STEAM theoretic framework, can lead to unique insights for embedding and linking left- and right-side neural algorithms to train AI/ML systems to enhance reasoning and understand causation. In other words, the door has been opened to researching AI/ML algorithms based on STEAM learning protocols which is a new area of research employing a different conceptual framework. The concept is further explored in Chapter 5.

Recall that Chapter 2 highlighted the various aspects of the brain-math-music synergy and its positive effect on STEM learning and engagement. Daugherty (2013) showed that science Nobel laureates were four times as likely to be musicians. Gordon et al. (2018) and Slater et al. (2017) described the synergy between the art of music and the science of sound on brain learning and concluded that experiences with music can shape the brain structurally and functionally. Gordon et al. further studied which parts of the
brain were affected by listening to music and how ultimately music could influence learning and engagement in the field of mathematics.

Additionally, Wu et al. (2015) suggested that an understanding of the harmonic spectral distributions found in music could be used to “bridge” musical harmony fluctuations with human emotions and inform STEM experts of the ways to positively enable STEM learning—particularly math engagement through the art of music. Wynn and Harris (2013) believed that a reciprocal benefit existed in joining artists (musicians) and athletes with mathematicians and scientists. Payton et al. (2017) demonstrated how dance art was related to interdisciplinary STEM problem-solving, collaboration, and critical thinking tasks. Grant and Patterson (2016) similarly suggested that the arts animated learning due to their experiential nature and because they stimulated creativity and critical thinking—equally valued in STEM pedagogy. Carrese, Kim, and Creeden (2013) stressed the importance of interdisciplinary learning in STEM that embraced the humanities. DiTullio (2018), Eagleman (2015), Kelly (2012), Perry (2002), and Reimer (2004) underscored the importance of stimulating brain activity and brain development through multidisciplinary learning and experiences. They cited how environmental stimuli can directly impact the emotion and values-based reward centers of the brain that in turn increased learning capacity and behavioral control. The next section examines the unexpected findings regarding group collaboratives and STEM engagement.

**Small group collaboratives and STEM engagement.** Springer and Stanne (1999) showed that small group learning in the classroom was key to STEM learning. Their study supported the idea of implementing more widespread small group learning in secondary and higher education institutions and was designed to inform institutional

However, the present study showed the opposite effect. Group collaboratives in general did not lead to productive outcomes despite the literature review findings to the contrary. Small groups produced less diverse ideas and outcomes; larger groups on the other hand, were inclined to engage in brainstorming activities along a wider range of dimensions and topics but required closer monitoring and management. Although the present study was confined to a specific research context, examining the issue in other contexts or settings would enhance an understanding of group synergies on STEM learning and engagement capacities. The next section examines the unexpected findings related to raising the visibility of mathematics as part of the STEM engagement strategy.

On integrating mathematics and other subject content. Compared with other Central New York high schools, the ESM High School STEM educators were very proactive in seeking ways to synergize aspects of STEM not only between the STEM subjects themselves but also with other subject areas. They were successful at incorporating science and technology in certain non-STEM classes but integrating mathematics was more difficult. Gaps emerged with attempts to introduce the fine arts into STEM because of the state education standards. Gaps also surfaced in attempting to
integrate math across various disciplines, which was unexpected. Effective connections were not being made between math and the fine arts like music.

The ESM teachers also explored the formation of multidisciplinary teams to synergize non-STEM subjects like English to improve science communications (reading, writing, and verbal skills). Math, however, was more difficult to include because of the inability to synchronize the math teachers’ schedules, curriculum constraints, a lack of defined goals, and other competing priorities. Again, the constraints on the curriculum forced the teachers to focus on meeting the Common Core State Standards instead of pursuing novel STEM programs that integrated mathematics and other subject content. Next, the influence of non-STEM subjects on STEM engagement and attrition are discussed as follows.

**Non-STEM interests driving STEM attrition.** The “reverse STEM effect” in which STEM-disposed individuals aspire to non-STEM fields such as music, was another unanticipated finding in the study. Anecdotal evidence pointed to interests in music that were amplified by exposure to related topics in STEAM. Indeed, STEAM provided a platform for envisioning the interplay of the musical notes, time signatures, and rhythmic patterns rooted in mathematics and science and that resonated with the creative process. Discussed next is an unanticipated finding regarding the larger role that artificial intelligence (AI) potentially plays in STEM pedagogy and engagement.

**Artificial intelligence and STEM learning and engagement.** The qualitative data gathered revealed dual perspectives on the link between STEM learning and artificial intelligence (AI) that was unanticipated and that prompted a further examination. The qualitative data suggested that AI expert systems could significantly
assist in STEM learning. STEM paves the way for futuristic AI research and
development occupations that do not exist today. In this case, STEM pedagogy drives
towards advancements in the field of AI research, but AI can also be used to effect
positive change in STEM pedagogy.

The coding of AI systems opens a Pandora’s box—negative societal biases
towards sexuality and gender, race/ethnicity, religion, politics, and along other societal
dimensions could implicitly creep into AI state machines. The AI expert systems would,
in effect, mirror those biases unless measures were taken to control, expunge, or process
them out. The emergent finding inspired a deeper examination of the relevant AI issues
on STEM learning within the intended scope of the study. The examination converged
on the converse perspective where AI drives advancements in STEM pedagogy and
content delivery.

The perspective highlighted a major gap in the literature opening avenues for
future research. For instance, an AI-assisted approach can be used to perform data
analytics on the myriad factors influencing STEM learning (inputs) to craft an optimal
STEM program (output) that best meets an institution’s specific needs (objective
function) for narrowing STEM gaps (outcome). Clearly, the approach has important
implications on STEM learning programs, interventions, and developing evidence-based reforms.

Surprisingly, a review of the literature did not uncover any significant findings on
the use of AI expert systems in STEM learning from the standpoint of curriculum and
lesson plan development that addressed specific institutional needs to narrow STEM
gaps. The LTM theory provided a basis for a STEM or STEAM theoretic framework that
can leverage AI for this purpose as will be discussed in Chapter 5. A useful association to consider is, pure logic and reason is to STEM as logic tempered by emotion and creativity is to STEAM, thus underscoring the advantage of a multidisciplinary strategy in AI that was not exclusive to STEM, and which has been elusive to date as a readily instantiable process. Scientists can easily program logic and reason, but programming reason tempered by emotion and creativity continues to be a challenging endeavor. Applying AI in the context of a conceptual STEAM theoretic framework “rezones” the STEM gap issue and is a candidate for qualitative grounded theory research to develop a revolutionary STEM engagement strategy.

The summary which follows will highlight the top STEM gap issues and contrast the data analysis results to reframe the major findings and outcomes facilitated by the research questions. The reframing employed the micro-to-macro process shown in Figure 4.1 to establish a basis for the implications and recommendations presented in Chapter 5. The reframing was necessary due to recurrent themes and common findings woven throughout and between the research questions which explored multiple STEM gap dimensions. The highlights and comparisons will be along six main headings as a fallout of the study as listed in Table 4.4. The headings are STEM affinity, institutional STEM curriculum, STEM learning environments and strategies, STEM marketing and messaging, organizational and individual factors, and social justice detractors. The top-level findings and conclusions on the STEM gap factors are summarized next.

**Summary of Results**

The following summary synthesized the top-level results and conclusions categorized across six main headings that emerged from the study aligned with the
research questions. The six headings tracked closely with the a priori codes that were used to establish the framework for the study to answer the research questions. The top-level conclusions were based on the recurrent or dominant themes that surfaced as drawn from the reduced data and study findings across all the focus groups. The conclusions were structured along the six main categories of STEM affinity, institutional STEM curriculum, STEM learning environments and strategies, STEM marketing and messaging, organizational and individual factors, and social justice detractors.

Texas Instruments (2019) offered a useful contextual framework for the conclusions presented below. STEM careers were seen through the lens of technological advancements in telecommunications, healthcare, and other industries. STEM education was viewed in terms of workforce preparedness for the jobs of the future such as those in artificial intelligence fields. The inequality in STEM preparedness was also covered. Texas Instruments prioritized three main principles each with a set of recommended actions that drive STEM education and that reinforced the findings of the present study. The Texas Instruments principles and main recommendations were as follows:

1. Raise awareness of each individual STEM discipline and associated synergies.
   a. Institute policies and measures to enable equitable access to first-class STEM education;
   b. Hold policymakers, institutions, and teachers accountable for delivery;
   c. Incorporate Career Technical Education (CTE) classes in secondary and higher education;
   d. Sponsor STEM professional development training for educators;
   e. Provide educators access to STEM industry subject matter experts;
f. Implement incentives to attract experienced STEM instructors; and

g. Leverage federal programs to promote and support STEM initiatives.

2. Show the connectedness between the individual STEM disciplines.

   a. Introduce school STEM content, topics, and experiences early on;
   b. Build parental and family support of STEM initiatives;
   c. Implement innovative instructional models such as project- or problem-based learning (PBL) with practical, real-world contexts;
   d. Institute an integrative STEM pedagogical approach;
   e. Provide open access to engineering design and CTE classes; and
   f. Offer purposeful in-school and cocurricular STEM activities and experiential learning opportunities.

3. Bridge STEM careers to STEM education and experience.

   a. Sponsor elementary STEM programs available to all young students;
   b. Require informed STEM career counseling;
   c. Enable technology access to all students and educators;
   d. Improve STEM marketing and outreach;
   e. Create an open school culture that is welcoming to families and others;
   f. Ensure the successful participation in STEM by underserved and underrepresented students and support STEM career pathways;
   g. Ensure informed school college/career counseling in STEM; and
   h. Engage in corporate industry partnerships and internship programs to extend STEM learning to the workplace.
The findings and conclusions that follow were resonant with the above principles and recommendations. Additional insights were provided that added to the body of knowledge on closing the STEM gap. The following discussions addressed the six main categories staring with STEM affinity. Each category referenced the research question that it answered as an outcome of the present study.

Regarding STEM affinity, which addresses research questions RQ1 and RQ2, a lack of institutional initiative to build and nurture STEM capacity beyond the limits imposed by the state education standards, especially for students with relatively high STEM affinity, was found to be a critical gap. STEM pedagogy must build on existing STEM affinity and nurture that affinity in a consistent, non-coercive way instead of blindly reaching out to recruit non-STEM candidates. “STEM” was ill-defined and tries to appeal to everyone instead of focusing on those with high STEM affinity. STEM outreach and marketing were unprepared to appeal to students with low STEM affinity. Whereas the students believed that the gap widens by failing to focus on students with high STEM affinity, the educators also considered students who were academically borderline in STEM. Failing to culture STEM affinity or implementing a forward-thinking STEM pedagogical model significantly contributed to widening the gap.

Regarding institutional STEM curriculum, which addresses research questions RQ1-RQ4, the STEM gap problem was exacerbated by two main factors: (a) a legacy of siloed learning burdened by NYSED constraints that was outdated, and (b) the failure to eliminate a monolithic STEM pedagogical model. Both the educators and the students were adamant about the negative role that the state testing standards and scripted
programs played in STEM engagement by limiting or preempting integrated, multidisciplinary curricula and practical problem-solving activities.

The state education system was inflexible and bureaucratic and not prone to enacting curricular reforms. The NYSED STEM curriculum limited the implementation of novel programs and perpetuated a “no child left behind” mindset. The dichotomous policies and messaging at the state level led to STEM programs that were implemented disjointly or incompletely due to inconsistencies in how the standards were applied across the grades. The focus on meeting state regional test standards and requirements was a major gap contributor; scripted state testing was considered outdated and set the academic system up for failure. Inaction to replace standards competency-based pedagogy with application- and outcome-based pedagogy was anticipated to worsen the gap problem. Maintaining the status quo of legacy, siloed, theoretical classroom learning that disconnects the STEM subjects and isolates non-STEM subjects contributed to disengagement by the time the students entered college.

The educators expressed greater concern over the lack of progress in being able to implement novel, multidisciplinary STEM learning programs that would benefit the students. On the other hand, the students felt that progress had been made but agreed that improvements were needed on this front. Where some novel STEM programs had been trialed, an over-paced series of program trials led to STEM information overload of detriment to STEM engagement.

Additionally, both the educators and students felt that STEM pedagogy was delivered inconsistently. The “disjointedness” of programs over time led to a confusing and bloated STEM education landscape, loss of focus, unachieved goals, eventual teacher
burnout, student disengagement. Both the educators and students agreed that the STEM messaging was often “forced.” Furthermore, the students felt that collaborative group activities worked well whereas the educators believed that any form of group activity was nonproductive and that the students lacked the soft skills to enable open and effective group dialogue.

The above factors combined to create a culture of fear of failure that was psychologically stressful and deterred students from pursuing a college STEM major or career. The gap was felt to widen due to the inability of school leadership, administration, and the STEM teachers to achieve reforms in current policies, procedures, and practices to improve STEM engagement outcomes upon graduation. Failing to engage the STEM, history, and language teachers as a group to reform multidisciplinary education coupled with uninformed career counseling further added to the gap.

Next, regarding STEM learning environments and strategies, which addresses RQ1-RQ4, a widening of the STEM gap was also attributed to the slow progress in pivoting towards a STEAM fabric via an integrative, multidisciplinary pedagogy model and the lack of a content driving curiosity mindset. Once again, the barriers were due to the constraints of the state standards and an uncertain rollout strategy. A monolithic, inflexible STEM pedagogical model hindered the rollout of customized programs intended to meet students’ needs and expectations and failed to exploit self-motivational theory to draw out one’s creative potential. The STEM learning environment that was intended to be more progressive, in effect collapsed and gave way to a more rigid and predictable environment. Although the educators considered current multidisciplinary synergies as scratching the surface and far from optimal, the students felt they had
reasonable exposure to such learning. The students and educators agreed that the scripted state testing standards impeded STEM engagement.

Uninformed career guidance coupled with a barrage of unilateral STEM messaging diminished one’s career choices and worsened the gap. The students tended to retreat and focus on personal interests without considering the larger academic outlook and career landscape. The students did not want to be pressured into STEM and wanted to make their own (informed) choices, but their ability to do so was limited.

Problems worsened when (a) the students were not taught to adopt an entrepreneurial mindset, (b) the teachers failed to inspire a culture of curiosity and the practice of inquiry, and (c) an institutional growth mindset was not cultivated. The school counselors failed to provide trustworthy career guidance, enable informed career decisions, encourage individual passions, and share the STEM vision by articulating the possibilities, options, and opportunities contributing to downstream attrition. A lack of clear communications, counseling, and coordination longitudinally at strategic points in a student’s career was felt to significantly contribute to the gap.

The STEM learning environment had a significant, direct influence on one’s level of STEM engagement and in modulating the gap. Clearly, undesirable experiences or non-conducive environments worked against cultivating high STEM-disposition. The environmental factors included motivational teachers and mentorship, creative hands-on activities that exploited multidisciplinary synergies to address real-world problems, group/team exercises inside and outside the classroom, and other factors all meant to inform STEM college/career decisions.
The STEM curriculum should highlight the natural connections within the STEM subjects and between STEM and the fine arts to evoke self-expression, creativity, and innovation. The curriculum should show math’s relevance to real-world applications and across multiple disciplines to make it less abstract and more relatable to life and career skills and for confidence-building. Understanding the link between intrinsic math anxiety and STEM engagement and how to overcome the fear of math were important to persistent engagement.

The teachers felt that their interventions assisted in overcoming intrinsic math anxiety and in coping with failure. Such interventions should be applied at the elementary/middle school level to train staff in effective math confidence building techniques and failure coping strategies. On the other hand, the students felt that the overall lack of training in how to embrace challenge and manage failure to build “STEM-hardness” significantly contributed to the gap. Furthermore, failing to instantiate a consistent, integrated, and multidisciplinary STEM-based model using practical examples and not developing cross-discipline content modules served to widen the gap.

In addition, multimodal content delivery was an important device for STEM learning and engagement. Multimodal content delivery exploits visual, tactile, and experiential learning for real-world problem contexts, along with PBL protocols for students to develop the soft skills useful in STEM for effective communication and social group interaction. The students and educators agreed that such techniques helped to stimulate creative independent and team learning and critical thinking to deepen STEM engagement. They further agreed that introducing non-STEM (arts and humanities) subjects as part of a progressive STEM curriculum provided for rich, impactful learning
contexts. However, music was not explicitly identified as a viable STEM engagement device despite the research findings in Chapter 2. Music was not used or tested in any type of intervention opening an avenue of possible research in the future.

A pedagogical environment that also tapped into optimal team collaboration and group size/mix guided by the teachers, and that fostered an integrated product team mindset early on for team building helped narrow the gap. The option should be given to STEM students for individual discretionary time before engaging in any group collaboration to effectively convert the “individual” mindset into a dynamic “group” mindset. The above devices, techniques, and training aids helped to develop a granular understanding of the multidisciplinary nature of STEM and in effect expanded the range of academic and career opportunities that can be considered.

The failure to prepare the high school STEM graduates for the rigors of the college STEM experience could cause them to switch to a non-STEM major or drop out of college altogether. The hope was to propel them into STEM as a college major or as a career choice by preparing them academically and emotionally to not fear challenge and embrace and manage failure as a learning experience. Also, from a STEM persistence viewpoint, it was incumbent on the educators and the institution to enable informed choice by balancing support of both college/professional and vocational/trade STEM opportunities.

Next, regarding STEM marketing and messaging, which addresses RQ1-RQ4, a major gap emerged because such outreach failed to build on students’ early exposure to STEM; in the students’ view, the high school programs lacked the multidisciplinary diversity and content they came to expect. The content and delivery did not always
match their interests or expectations when compared to their earlier experiences. On the other hand, the educators saw inconsistencies in “capturing” STEM interest at a young age and maintaining the continuity of STEM programs prior to and during the high school years. The students felt that forcing the STEM agenda rather than nurturing STEM engagement at a young age had detrimental outcomes.

Failing to expand opportunities that matched specific interests or needs in support of STEM career pursuits and disempowering informed freedom of choice were equally harmful to engagement. The students saw a need to step in and expand the advertising of STEM programs to elementary/middle school grades via personal visits and presentations. Such outreach would be a way for the STEM students to convey their individual experiences and knowledge gained, friendships formed, and the many fun group activities and learning opportunities to proactively close the gap.

The students furthermore felt that the forceful STEM messaging, which puts college-based careers way ahead of vocational/trade-based pursuits, devalued the message. The marketing and outreach failed to provide a balanced message on the merits of both college/professional and vocational/trade career pathways. The imbalance limited choices and failed to meet expectations in terms of traditional STEM career fulfillment.

The educators on the other hand thought that the STEM outreach was not well-defined and lacked cross-disciplinary associations, calling into question the effectiveness of today’s outreach tactics on persistence. The educators and students agreed the message was clear that a college STEM degree was preferred over a technical vocational/trade certificate, and that the messaging was over-hyped and highly biased.
Both the students and the educators warned that forcing or over-propagandizing such a message could certainly disengage STEM interest because it diminished choice and dampened self-interests or personal pursuits. The STEM outward messaging was confusing and conflicted, and where the goals of recruitment were ill-defined vis-a-vis enhancing workforce preparedness.

Hyping STEM as a panacea for workforce preparedness but where STEM education was not consistently defined and the strategies for developing and implementing high-impact STEM programs was uncertain, adds to the disengagement. The messaging was vague and open to interpretation, leading to a wide array of programs that on one hand, were beneficial in terms of diversity, but on the other hand, were confusing and inconsistent with varied expected outcomes. Again, it came down to defining what STEM meant and why it was important for workforce preparedness.

The combination of poor marketing and advertising of STEM offerings and the myriad non-STEM classes and conflicting schedules exacerbated the problem and denied valuable learning opportunities for the students. The marketing, structuring, and scheduling of STEM classes and electives forced the students to choose from myriad options that became confusing or overwhelming. Failing to crystallize the STEM message and conducting an ineffective STEM marketing/advertising campaign that failed to raise STEM awareness led to frustrating outcomes. The students became less aware and consequently less empowered to make independent, informed academic and professional career choices best suited to their interests, thus contributing to the gap. Although STEM had been highly touted at different forums often at the exclusion of all
else, the publicity and published materials did not reflect the same level of enthusiasm and therefore, STEM’s importance has struggled with an identity and visibility crisis.

Whereas the students’ focus was on the outward messaging used to recruit students into the STEM program, the teachers’ focus was more on the inward messaging to students once they were “captured” into the program. The STEM marketing strategies and inward messaging often fostered misconceptions about the program that set STEM students up for failure upon entering college or the workforce. The high school students—a vulnerable population—were often unsure of their college/career goals and at times felt pressured into considering STEM, and where non-STEM pursuits were frowned on. The graduating students were in some cases unprepared or uncertain of their postgraduation plans and pursuits, thus contributing to the gap. The problem pointed back to the school career guidance issue. The students also thought the messaging neglected to balance multiple factors influencing career decisions such as labor demand, advancement opportunities, and so on against purely personal or salary considerations.

Another troubling aspect of STEM marketing concerned itself with the specific nature of the message. The barrage of conflicting messages like “STEM is harder than other subjects,” “grades are key,” or notions of elitism in STEM, or having the “right credentials,” were thought to flip the engagement switch to “off” between high school graduation and the first year of college.

The students saw STEM outreach as not openly inclusive of disadvantaged, underserved, or underrepresented groups and that it failed to downplay elitist attitudes and socioeconomic or sociocultural stereotypes. The educators saw a forced marketing blitz to fill artificial quotas for females in STEM and that had a polarizing effect on
STEM attitudes. The resultant pressure on females had diminished their right to choose freely fields or professions of interest—*failing to build on one’s passion, talent, fit, and choice regardless of gender*. It was also felt that questioning females about their STEM versus non-STEM choices casted doubts in their minds and only served to widen the gap.

The students thought the STEM marketing, in the context of social justice, failed to address concerns over gender parity, equity, equal opportunity for high-paying jobs, reward and fulfillment, financial security, and personal happiness. On the other hand, the educators thought the marketing and outreach failed to promote STEM as an enabler for competitive skills development in fields that embodied social justice and social equality touchpoints. The students further thought the STEM marketing/outreach failed to address technology’s role in society for improved quality of life; opportunities and incentives for underserved groups; philanthropy and humanitarian needs; contributions to job growth and societal financial health; and corporate or other organizational outreach. The educators on the other hand were concerned over perpetuating barriers to STEM entry via mixed messaging that alluded to some STEM fields being more competitive than others, all socioeconomic and sociocultural factors considered.

Next, regarding organizational and individual factors, which also addressed RQ1-RQ4, an earlier theme resurfaced: organizational incapacity to build and nurture STEM affinity beyond the limits imposed by state curriculum standards by failing to implement progressive STEM pedagogical best practices. The students emphasized the “systemic” multiorganization inertia that worked against implementing a near-term, progressive STEM strategy and the high school failing to keep pace due to protracted inaction and a reticence to change by state education agencies. The educators on the other hand focused
on three concerns that they felt contributed to the gap: (a) the lack of implementing STEM pedagogy best practices, (b) the lack of informed school counseling, and (c) systemic institutional policies that fueled social injustice conditions.

The educators felt STEM disengagement was the result of the institution failing to proactively implement proven best practices even beyond progressive, multidisciplinary pedagogy. The best practices here referred to operating at deeper levels of mutual trust building, assessing lesson effectiveness and course correcting as necessary, active student outreach, and providing nurturing support environments. They again cited the lack of prepared school counseling and informed guidance on the realities of pursuing a STEM field of study or work. The failure to dispense authentic, informed guidance to students about STEM and not enabling them to autonomously make choices tempered by expert guidance was a major detractor to engagement and contributed significantly to the gap.

The students and educators agreed on STEM career development strategies that considered the larger “life outlook” and cultural values over purely salary/compensation and economic incentives. The “bigger picture” outlook considered the balance of salary against other vital factors such as personal or aspirational interests, self-efficacy, self-improvement, advancement potential, market demand, willingness to “invest” in the process, and positive social contributions. The related issue again here was the need to be inclusive of the technical vocational trades in career counseling and enabling choice in the matter by weighing the cultural values. Some students who are interested in STEM trades felt disenfranchised from mainstream STEM opportunities.

Several factors influenced outcomes for ensuring complete, informed, and reliable academic and career guidance. The factors included (a) the lack of direction given to
teachers by administrators, (b) sporadic coordination between the administration and teachers regarding counseling, (c) the myriad electives or class offerings, and (d) other “distractions” that together created a confusing STEM pedagogical landscape. The most critical factor was the changing role of school counselors in recent years.

According to the students and teachers, the school counselors were more preoccupied recently with managing students’ social-emotional and behavioral issues daily. Dispensing informed career guidance became a secondary endeavor or altogether absent; instead, career guidance was now routinely delivered by educators, but the teachers considered themselves unprepared to provide counseling. An additional concern was how the restructuring had affected the students who were outside the STEM teachers’ spheres of influence begging the question, “What type of counseling were they receiving?”

The lack of informed, engaged, and reliable career counselors dedicated to their role, and the absence of dependable and insightful STEM career guidance were significant contributors to the STEM gap—individually corroborated by the students and educators. The absence of teacher/counselor/mentor support systems including informed guidance, and the failure to prepare students for the rigors of multidisciplinary group STEM learning in college has worsened the gap. Confusion, uncertainty, and eventual disillusionment set in without a roadmap for the journey.

Anecdotally, when a student jumps into the STEM pool (college in this case) and finds the temperature (workload, enjoyment level, and other experiential factors) either too hot (difficult, challenging) or too cold (nonchallenging, uninteresting) for their tastes, they will either abruptly leave (drop out) or gradually exit (switch majors) and seek other
pools or shores (labor force). The anecdote and metaphors offered reasonably describe how the STEM gap can be affected.

Indeed, the lack of dedicated, informed counseling and the mixed messaging on STEM set up yet another barrier that contributed to the gap. First, misconceptions were often socialized regarding the rigors and demands of the STEM fields compared to the perceived “lesser” demands of the non-STEM fields. Second, the students were swayed by messages on the higher benefit-to-risk ratios for non-STEM majors in terms of competitive salaries and benefits, reduced commitment and scholastic intensity, high job demand, and lower stress making it attractive for them to abandon any notion of a STEM career.

The considerations of risk versus reward, expectations and demands, stress or anxiety, and negative outcomes were especially important in the cases of students with low STEM affinity who were funneled into the STEM pipeline. At the same time, the high school was expected to produce college-ready, “master class” STEM scholars. However, the students were not always well-positioned in the pipeline to accommodate needs. The teachers felt that the responsibility of producing master class STEM students should be shifted to the colleges, although it was agreed the high school should continue to support college-level preparation. Higher education failed to proactively ensure more successful outcomes for STEM students including viable safety nets or alternatives due to a *sink or swim* mindset. The lessons learned can be used to advise secondary institutions of the factors contributing to disengagement and ways to mitigate them.

Whereas the students’ view of institutional “systemic” *malaise* reflected the state education agencies’ weak support of progressive STEM reforms, the educators’ view on
the multiple systemic issues and institutional shortcomings were directed at inherent system biases. They referred to “hidden” biases that favor (or deny) STEM educational opportunities based on privilege, class, wealth, and power—a social injustice context. They saw the lack of action or not taking more aggressive steps toward change as a means of widening the STEM gap and contributing to middle class erosion as a socioeconomic issue.

Several other recurring themes contributing to the gap resurfaced relating to social justice. The themes included (a) perpetuating stereotypical beliefs on the expected roles of males and females or underrepresented groups, (b) failing to expose females to STEM content at a young age, and (c) STEM marketing strategies that limited or disempowered females to make their own choices. Additionally, negative peer attitudes on pipelining females toward STEM fields, knowing that it is a male-dominated and highly competitive, can daunt the pursuit and contribute to widening the gap. However, some females felt as though they were being coerced into STEM without truly understanding why based on the facts. They would rather have taken charge of the decision to split off into STEM and/or non-STEM classes or to seek a customized program that appealed to their specific interests. Although not endemic to ESM High School, limiting choice on the matter in this way contributed to an erosion of STEM interest.

Other important factors contributing to the gap ranged from family values on STEM higher education to improving secondary school STEM educational policies and practices to enable a better STEM experience after high school. For instance, the students thought that a lack of positive family support and peer encouragement affected
their decision to pursue a STEM field, but it can be a double-edged sword. As stated previously, peer pressure can work against STEM engagement for a variety of reasons.

Also, families motivated by economic incentives can drive their children to achieve good grades at any cost to qualify for STEM college scholarships for the purpose of reducing their financial burdens; however, students who were academically unprepared, uncertain, or perhaps disillusioned by STEM in college may switch majors or drop out, hence contributing to STEM attrition. Similarly, financial incentives in non-STEM fields of study can force students to rethink their interests in STEM. The ongoing tensions must give at some point to avoid contributing to STEM attrition. In other words, financial considerations alone were insufficient to make informed decisions on pursuing STEM while being mindful that STEM was not for everyone.

The educators on the other hand were more fearful of promulgating STEM elitism—a populist view where STEM pursuits were reserved for those who met certain requirements. Higher education itself either intentionally or inadvertently promoted an image of elitism and created a culture of inequity that added to disenfranchisement. The concern points back to the idea of STEM democratization which was addressed by both the students and the educators. STEM options for 2- or 4-year colleges, vocational trades, scholarships, internships, job market and timelines, and associated risks/benefits should be considered on an equal footing.

Stated another way, STEM pursuits were not restricted to a 4-year degree college program in a STEM field of study as a minimum. The educators went a step farther. In their view, the academic system failed to cultivate a unicorn mindset—a workforce issue—by not forging stronger intersections between the science/technology and
art/design domains, reinforcing the notion that human beings are naturally *STEAM creatures* and not *STEM creatures*.

Additional gap contributors related to *Organizational and Individual Factors* included a failure to connect the high school STEM programs with industry and the business workplace; failing to increase the number of internships, corporate scholarships, and college credits; failure to adapt educator skills across multiple subject areas to help shape the new STEM pedagogical landscape; and not recruiting industry experts to provide practical STEM training experience to inspire and motivate students.

According to the students, ESM High School was on the right path for increasing STEM engagement, but improvements in rolling out progressive STEM curricula and other policy reforms were cited. On the other hand, the educators felt that although progress had been made, it was slow to arrive and the school in certain respects was behind in meeting a true, progressive and impactful STEAM agenda. ESM High School must further shift its focus on student-career success in STEM in view of the above barriers and gaps. STEM engagement suffers if the student encouragement towards STEM is weak or sporadic.

Finally, regarding social justice detractors, which addresses RQ3 and RQ4, according to the educators, one of the main contributors to the STEM gap was a failure to recognize the larger socioeconomic and sociocultural disparities that exist. A greater number of class and race issue were prevalent in academia and careers that such groups continued to face and that outweighed the gender-bias issue. The relevant socioeconomic and sociocultural disparities and their impact on the STEM gap were tied to federal and state legislation that limited or was devoid of financial assistance or other incentives.
According to the educators, federal policies particularly mandated that scientific research and technology companies, especially those doing U.S. national defense work, meet hiring quotas across gender, race/ethnicity, and other socioeconomic and sociocultural demographic criteria. The policy created conditions that could lead to the hiring of unqualified candidates just to fill quotas causing workforce tensions—an imbalance in workforce supply and demand of certain types of skilled labor and positions that could be difficult to fill—rather than hiring based on talent and ability. The potential mismatch has led to an industry-workforce gap that contributes to widening the STEM gap. The policy is ill-conceived and prone to failure because it neglected the scientific and the labor force data to launch a truly informed campaign albeit, the policies supported equal opportunity goals.

Per the educators, the STEM gap expands without a resident, organizational support system in place to nurture the desired STEM skill sets and extend the ecosystem of opportunities for all social groups. Failing to democratize STEM by not mitigating unfair practices and using coercion to favor one demographic over another regardless of gender or socioeconomic or sociocultural status, has led to attrition and a widening of the gap. The students’ view was that the local technology companies failed to step up active outreach and engagement to offer internships, engineering scholarships, and financial aid/incentives for disadvantaged or underserved STEM students, thus worsening the gap.

The educators further believed that perpetuating gender-bias stereotypes and failing to cultivate the associations between strength and empowerment and being a female in STEM also worsened the gap. Not exposing females to STEM at a young age to establish a foundation to build upon in their later years was reiterated by the educators
as a risky strategy, along with questioning or challenging their career decisions. The
students on the other hand felt that females should take a proactive stance on the growth
in the number of women entering the STEM fields and breaking the “glass ceiling” by
sending a message on the disparities to show that changes are afoot to narrow the gap.
Although the STEM fields are male dominated, it was important to recognize that
socioeconomic and/or sociocultural factors outweigh gender bias alone in contributing to
the STEM gap.

As previously mentioned, several unexpected findings were also revealed in the
study. The findings addressed (a) the changing role of school counselors that had
negatively impacted efforts at providing reliable STEM career guidance, (b) misalignments between STEM recruiting strategies and STEM affinity, (c) the non-
impact of music on STEM engagement, (d) small group collaboratives that were deemed
problematic in a STEM engagement context, (e) difficulties in integrating mathematics
with other subject content including classroom delivery, (f) non-STEM interests driving
STEM attrition, and (g) the role of artificial intelligence (AI) in STEM learning and
engagement. The AI theme emerged several times during the data collection.

Some of the teachers were concerned about the direction that the AI field of study
was taking in STEM education and career development. Anecdotal evidence highlighted
the impact of classes that integrated topics on AI, society and humanity, and literature
with beneficial results on creativity and multidisciplinary learning. On the other hand,
several teachers expressed concerns about how societal biases regarding sexuality,
gender, race, religion, and politics were being implicitly coded in AI machines and
systems, and how the present study could help elucidate the matter. If the implicit biases
were not controlled, then the AI-driven systems and machines would most likely reflect those same biases. The AI theme was briefly addressed in Chapter 2.

The unanticipated findings on AI inspired further research into the formation of a potential grounded theory rooted in the methods of Strauss and Glaser (Charmaz, 2006; Glaser, 1995; Strauss & Corbin, 1994; Van Niekerk & Roode, 2009). The approach would be to operationalize the findings gathered from the studies on STEM pedagogy, engagement, and persistence such as the present study. A novel AI-assisted method could output optimal solutions for enhancing STEM engagement in the form of progressive curricula, lesson plans, and rollout strategies. The AI theme will be further discussed in Chapter 5.

Lastly, STEM should be exploited as a tool to “remedy” ill-posed (political) messaging that “lacked the science” to preclude disenfranchising or isolating social groups. The lack of policy reforms to restructure STEM education must be overcome before true change can take place and the benefits realized. The next chapter will present the implications of the above findings and conclusions, limitations, recommendations, and provide the conclusion for the study.
Chapter 5: Discussion

Introduction

The extant body of literature validates the benefits of implementing pedagogical reforms and interventions to enhance STEM engagement and persistence. However, educational institutions at large have been slow to embrace reforms either for budgetary, political, or other reasons, and the interventions remain experimental at best and vary from one institution to the next. Thus, the STEM pedagogical landscape, as defined by a set of recommended policies and best practices from the educational institutions themselves, remains fragmented and highly inconsistent regarding their implementation. Some reforms and interventions are more aggressive than others, and the outcomes are often varied, immeasurable, and uncertain. Furthermore, an ongoing struggle exists in academic circles regarding the adoption of STEM-based versus STEAM-based curricula, including variations thereof such as STREAM, with the “R” standing for “research.” Consider that by nature, human beings are more eclectic “STEAM creatures” than they are pure “STEM creatures.” This point sets the stage for the chapter discussions which follow.

Additionally, the mere fact that U.S. academic institutions acknowledge a STEM gap problem exists and are attempting to fill the gap by trialing interventions is certainly a hopeful step, but the goal remains elusive again because of inconsistencies in their adoption, implementation, and with the varied outcomes. The academic “industry” is unsure of the best strategy to employ. Indeed, the present research does not endorse a
STEM versus STEAM or any other pedagogical model as such. Notwithstanding, the literature shows that certain best practices infer positive outcomes and warrant careful examination as was accomplished in the context of ESM High School’s Spartan Academy STEM Program.

To further set the stage for the ensuing discussion, recall in Chapter 1 the evidence showing the US performing poorly in STEM education despite efforts to expand academic STEM programs over the past 20 years (Gonzalez & Kuenzi, 2012). The STEM engagement gaps continue to widen contributing to an increase in STEM pipeline leakage—indeed, the U.S. STEM pipeline is broken. Chapter 1 examined the current state of STEM pedagogy highlighting studies that addressed experimental interventions or institutional reforms designed to increase STEM engagement and reduce the gap. The research on the causes for the STEM gap over the past 10 years points to the growing importance of new, pedagogic interventions. The interventions employed variants of integrated, interdisciplinary active learning in place of traditional, siloed STEM learning protocols (Glancy & Moore, 2013). The implications of this are further addressed below.

Also recall the Pew Research Center report (2017) that claimed the US fell in the middle of the 2015 Program for International Student Assessment (PISA) test scores in science, math, and reading compared to all other countries around the world as shown in Figure 1.1. The published report identified at the beginning of the research study ranked U.S. students 40th worldwide in math literacy. The International Activities Program National Center for Education Statistics (2015) further cited a decline in math aptitude during the prior two assessments where U.S. students fell below the math baseline proficiency level, revealing a gap between the national STEM push and demonstrated
proficiencies or outcomes. The most recent findings show that the STEM gap problem persists (Camera, 2019; International Activities Program National Center for Education Statistics, 2018; OECD iLibrary, 2020).

According to Camera (2019), the most recent PISA scores for U.S. students in science and reading were marginally above average and in mathematics were marginally below average, thus showing no significant change since the prior-years’ performance ratings. Camera also noted that 30 countries outscored the U.S. students in math and that the gap is widening between the top- and lower-performers. PISA, developed by the Organisation for Economic Cooperation and Development (OECD)—an intergovernmental consortium of 37 mostly industrialized countries, is administered every 3 years to more than 600,000 students in 79 countries and continues to provide useful benchmarks to measure STEM-based proficiencies. Unfortunately, for many U.S. students virtually little to no progress has been made over the past 20 years—a finding that the STEM community finds troubling and that exacerbates concerns over the STEM gap problem.

Recall, the Smithsonian Science Education Center (2020) reported that nearly 78% of high school graduates fell short of meeting “readiness benchmark levels” for freshman college courses in mathematics, science, or reading yet the demand for STEM talent continues to grow. Approximately one-third of all STEM majors in U.S. colleges and universities change to a non-STEM course of study during their freshman year. Clearly, the U.S. STEM pipeline is broken.

Beyond the educational event horizon lies the workforce landscape. Recall that since the Industrial Revolution, STEM jobs have doubled as a proportion of all jobs in the
US with a three-fold rate increase in STEM-related jobs over non-STEM jobs from 2000 to 2010, and as many as 2.4 million STEM jobs remained vacant through 2018 (Smithsonian Science Education Center, 2020). According to Lazio and Ford (2019), millions of STEM jobs in the US remain vacant. The true number likely exceeds 8.6 million STEM job vacancies representing approximately 6.2% of U.S. workforce employment. It is projected that the number of STEM jobs will grow to 13% by 2027 and the gap is anticipated to further widen. In response to this, the Trump administration is pushing a national plan to create nearly 3.5 million STEM jobs by 2025, but there is no clear plan in place to effectively feed the STEM pipeline to meet the projected demand. Today, nearly 60% of employers are facing the challenge of filling millions of open STEM positions in a timely way—the heart of the dilemma. Employers are finding it extremely challenging to hire U.S. STEM graduate students with advanced masters and doctorate degrees and often have no choice but to consider foreign nationals to fill important STEM research positions. Simply stated, the STEM jobs are not being filled at a rate fast enough to match recruitment goals and that overcome losses due to attrition. Once again, the U.S. STEM pipeline is broken. The implications of this basic finding from an ESM High School perspective are presented below.

In view of the above background and considerations, this chapter highlights the key study findings and their implications and limitations related to ESM High School’s Spartan Academy STEM Program. The implications are presented factually and are not intended to be generalized to other contexts, populations, or institutions. The research study makes no judgements regarding any STEM interventions by ESM High School but attempts to address their long-term ramifications in the context of the research questions.
posed. It is safe to state that even if ESM High School is not a willing contributor to the STEM gap problem, it is certainly in the critical path of the dilemma and in offering ways to help fill the gap. Chapter 5 addresses this crossroads issue and additionally provides recommendations for higher education teacher preparedness programs, secondary school STEM teachers, and state education policy makers.

Indeed, the purpose of the case study was to examine the efficacy of proposed reforms and interventions on students’ STEM engagement and persistence. To that end, the case study methodology discussed in Chapter 3 provided for a reasonable representation and sample size of participants to synthesize the broader student and educator perspectives on the matter. The integrated perspectives of the STEM students and educators involved in ESM High School’s STEM program provided for well-rounded and meaningful qualitative results. Multiple themes surfaced during the data analyses that led to the findings summarized in Chapter 4. No qualitative studies of a similar breadth and depth were found to exist, and the finding and implications presented in the next section were well-aligned with the research questions reiterated as follows:

1. From the student’s perspective, how does participation in a STEM learning program stimulate or deter interest in pursuing a STEM major in college or as a career choice?

2. From the perspective of the educator, how do current STEM programs contribute to or detract from STEM persistence after high school, during college, and as a career choice?
3. From the standpoint of students and educators, why might STEM persistence or sustained STEM interest upon/after high school graduation be on the decline?

4. From the perspective of students and educators, how can interest in pursuing a STEM major in college or a STEM career be increased?

Recall that the focus group questions posed across the student and educator participant groups were segmented to inform a specific research question. Furthermore, separate sets of focus group questions and research questions were individually posed to obtain student and educator perspectives. The focus group and research questions overlapped to a certain degree to facilitate the synthesis of results across all the focus groups. In effect, individual focus group insights were used to generate aggregate group insights to identify areas of convergence or divergence and sift out the dominant themes and implications as discussed in the next section.

**Implications of Findings**

Following an analysis of the aggregate data results, six key findings emerged from the study each having associated subthemes and corresponding implications. The key findings were summarized in Chapter 4 and their implications are further derived below. The six findings track closely with the a priori codes that were used to establish the framework for the study to answer the research questions and progressively build upon the findings and conclusions presented in Chapter 4. Once again, the top-level findings are based on the recurrent or dominant themes that surfaced during the data gathering portion of the study and are related to *STEM affinity, institutional STEM curriculum, STEM learning environments and strategies, STEM marketing and*
messaging, organizational and individual factors, and social justice detractors. The implications related to STEM affinity are discussed next.

**Finding 1: STEM affinity**—STEM outreach programs must be designed that resonate and nurture interest with purposeful outcomes. A lack of institutional initiative to build and nurture STEM capacity beyond the limits imposed by the state education standards especially for students with relatively high STEM affinity was found to be a critical gap. STEM pedagogy must build on existing STEM affinity and nurture that affinity in a consistent, non-coercive way instead of blindly reaching out to recruit non-STEM candidates. “STEM” is ill-defined and tries to appeal to everyone instead of focusing on those with high STEM affinity or potential. STEM outreach and marketing are unprepared to appeal to students with low STEM affinity.

Alternatively stated, those individuals with high STEM affinity will naturally be drawn to STEM and efforts should be made to sustain their interests by providing for a challenging yet nurturing STEM learning environment; on the other hand, those with moderate STEM affinity, including students with borderline STEM aptitude or interests, will resonate more with STEAM and more creative nurturing will be needed to draw them into STEM; finally, those with low or no STEM affinity are likely to be drawn almost exclusively to non-STEM pursuits and much more effort will be needed to persuade them into STEM with potentially diminishing returns. Additionally, not culturing STEM affinity or implementing a forward-thinking STEM pedagogical model significantly contributes to widening the gap even for individuals with high STEM affinity. The next section further discusses how the institutional STEM curriculum must evolve to increase STEM engagement as follows.
Finding 2: *Institutional STEM curriculum*—replacing standards competency-based STEM pedagogy with application- and outcome-based STEM pedagogy. The STEM gap is exacerbated by two main factors: (a) a legacy of siloed learning burdened by NYSED constraints that is outdated by today’s standards, and (b) the failure to eliminate a monolithic STEM pedagogical model. Scripted state testing standards play a negative role in STEM engagement by limiting or preempting integrated, multidisciplinary curricula and expanding practical problem-solving activities. The state education system is inflexible and bureaucratic and not prone to enacting curricular reforms. The NYSED STEM curriculum limits teachers’ latitude in implementing novel strategies and perpetuates a “no child left behind” mindset.

The dichotomous policies and messaging at the state level can lead to STEM programs that are implemented disjointly or incompletely due to inconsistencies in how the standards are applied across the grades. The effect is reduced STEM engagement. The focus on meeting state regional test standards and requirements is a major gap contributor; scripted state testing is considered outdated and sets the academic system up for failure. Inaction to replace standards competency-based pedagogy with application- and outcome-based pedagogy will serve to worsen the problem. Maintaining the status quo of legacy, siloed, theoretical classroom learning that disconnects the STEM subjects and isolates non-STEM subjects from STEM contributes to disengagement by the time the students enter college or the workforce.

The educators are concerned over the lack of progress in being able to implement novel multidisciplinary STEM learning programs that would benefit the students. Although the students feel that some progress had been made, they also believe that
improvements are needed on this front. The finding and its implications are consistent with the literature on the importance of integrated, interdisciplinary learning (Belland et al., 2015; Brown, 2012; Carrese, Kim, & Creedon, 2013; Gottfried, 2015; Kertil & Gurel, 2016; Kezar & Gehrke, 2017; Sanders, 2012; Sriraman & Lesh, 2007; Stage & Kinzie, 2009). Whereas some novel STEM programs have been trialed, an over-paced series of such program trials leads to STEM information overload and is thus a detriment to overall STEM engagement. Additionally, STEM pedagogy is inconsistent and disjointed. The “disjointedness” of programs over time can lead to a confusing and bloated STEM education landscape, loss of focus, unachieved goals, and eventual teacher burnout and student disengagement.

Next, the STEM messaging is often “forced,” and the group collaboratives are marginally effective. The finding and its implications contrast with those identified in the literature attesting to the importance of small-group collaboratives (Sriraman & Lesh, 2007; Springer & Stanne, 1999). Although the students feel that collaborative group activities work well, the educators are of the opinion that any form of group activities tends to be nonproductive and that the students lack the soft skills needed for open and effective group communication. The gap in understanding must be reconciled if collaborative engagements are to be an effective tool in STEM learning.

The above factors combine to create a culture of fear of failure that leads to stress and could deter students from pursuing a college STEM major or career. The gap widens due to the inability of school leadership, administration, and STEM teachers to push for reforms in current policies, procedures, and best practices intended to improve STEM engagement upon graduation. The finding and its implications strongly support the
literature findings pertaining to STEM teachers’ level of satisfaction and willingness to promote creative STEM activities where the technology educators have the greatest chance of influencing STEM reforms (Ernst et al., 2018). The findings and implications are further consistent with the studies by Ernst et al. and Kezar and Gehrke (2017) suggesting that institutions establish policies and rewards to motivate faculty to spur reform. Not effectively engaging the core teachers across STEM, history, and language disciplines to strive for change through improved multidisciplinary education coupled with informed career counseling further exacerbates the gap. The implications of STEM learning environments and strategies are discussed next.

Finding 3: **STEM learning environments and strategies**—increasing engagement via an integrative, multidisciplinary STEAM-based pedagogy model. A widening of the STEM gap is also attributed to the slow progress in pivoting towards a STEAM *fabric* via an integrative, multidisciplinary pedagogy model and reinforcing a *content driving curiosity* mindset. Once again, the finding and its implications are consistent with the literature on the importance of integrated, interdisciplinary learning (Belland et al., 2015; Brown, 2012; Carrese, Kim, & Creeden, 2013; Gottfried, 2015; Kertil & Gurel, 2016; Kezar & Gehrke, 2017; Sanders, 2012; Sriraman & Lesh, 2007; Stage & Kinzie, 2009). The barriers are due to the constraints of the state standards and an uncertain rollout strategy. The state testing standards and scripted programs are simply an impediment to STEM engagement. A monolithic, inflexible STEM pedagogical model hinders customized programs to meet students’ needs or expectations and fails to exploit self-motivational theory to draw out one’s creative potential.
STEM learning environment in effect becomes less nurturing, more rigid and predictable, and less stimulating or engaging.

Next, the lack of informed career guidance coupled with the barrage of unilateral STEM messaging diminishes one’s career choices, discourages interest, and adds to the gap. The students tend to retreat and focus on personal interests without considering the larger academic and career picture. In other words, the students do not want to be pressured into STEM and would rather make their own (informed) choices, but their ability to do this is limited. Furthermore, the gap worsens when (a) the students are not taught to adopt an entrepreneurial mindset, (b) the teachers fail to inspire a culture of curiosity and the practice of inquiry, and (c) an institutional growth mindset is not cultivated. STEM engagement suffers when school counselors fail to provide sound career guidance, fail to enable informed career decisions, do not encourage individual passions, and are unable to share the STEM vision by articulating the possibilities, options, and opportunities. Hence, a lack of clear communications, counseling, and coordination at strategic points in a student’s career significantly contributes to the gap. This was an unanticipated finding but one that is critical to address in filling the gap.

Additionally, the STEM learning environment has a significant, direct influence on one’s level of STEM engagement and in modulating the gap. Clearly, undesirable experiences or non-conducive environments will work against cultivating high STEM-disposition. The environmental factors include motivational teachers and mentorship, creative hands-on activities that exploit multidisciplinary synergies to address practical problems, meaningful and impactful group/team exercises inside and outside the classroom, and other factors all meant to inform and formulate STEM college/career
decisions. The findings and implications corroborate the literature on the importance of curating and nurturing active, immersive learning with real-world contexts and providing educator mentorship (Allen et al., 2016; Belland et al., 2015; Brown, 2012; Christensen et al., 2015; Carrese, Kim, & Creeden, 2013; Gottfried, 2015; Jackson et al., 2014; Kertil & Gurel, 2016; Kezar & Gehrke, 2017; Sanders, 2012; Sriraman & Lesh, 2007; Stage & Kinzie, 2009). Although the findings on the efficacy of group/team collaboratives were mixed, methods should be identified to make collaboratives an effective tool as part of curating a nurturing STEM learning environment. Again, the finding and its implications contrast with those identified in the literature attesting to the efficacy of small-group collaboratives (Sriraman & Lesh, 2007; Springer & Stanne, 1999).

A pedagogical environment that taps into optimal team collaboration and group size/mix guided by teachers, and that fosters an integrated product team mindset early on for team building will help narrow the gap. The option should be given to STEM students for individual discretionary time before engaging in any group collaboration to effectively convert the “individual” mindset into a dynamic “group” mindset. The above devices, techniques, and training aids help develop a deeper understanding of the multidisciplinary nature of STEM and in effect expand the range of academic and career opportunities that can be considered.

The curriculum should highlight the natural connections within the STEM subjects and between STEM and the fine arts to evoke self-expression, creativity, and innovation. The curriculum should show math’s relevance to real-world applications and across multiple disciplines to make it less abstract and more relatable to life and career skills and for confidence-building. Understanding the link between intrinsic math anxiety
and STEM engagement and how to overcome the fear of math are important for persistent engagement. Teacher interventions assist in overcoming intrinsic math anxiety and in coping with failure. Such interventions should be applied at the elementary/middle school level to train staff in effective math confidence building techniques and failure coping strategies. The students feel that the overall lack of training in how to embrace challenge and manage failure in building “STEM-hardness” significantly contributes to the gap. Failing to instantiate a consistent, integrated, and multidisciplinary STEM-based model using practical examples and not developing cross-discipline content modules serves to widen the gap. The finding and its implications confirm the literature on the importance of exploiting interdisciplinary connections through mathematics including relationships to non-STEM influencers (Hutto et al., 2015; Korpershoek et al., 2011; Moakler & Kim, 2014; Stieff & Uttal, 2015; Tobias, 2014; von Károlyi, 2013; White et al., 2012).

Recall that Lesh and Doerr (2003) defined an interdisciplinary translation as mapping a concept or knowledge-based embodiment from one representation to another as Figure 5.1 depicts. Integrated STEAM learning fits this approach and can be thought of as an amalgam of the concepts, ideas, communicative skills, and higher-order thinking that links STEM and non-STEM disciplines (denoted by the “A”) together expounding on the notion that STE(A)M is more than merely the “sum of its parts,” which again, is consistent with the tenets of emergent theory (Charmaz, 2008; Wilson, Broughan, & Hillier, 2017). An object, concept, or notion can be represented in multiple dimensions (symbolically written, diagrammed, orally expressed, using similarities based on experience, and via physical or tactile manipulations).
Lesh’s translation model (LTM) offers a viable framework for acquiring a conceptual understanding of the interrelationships across the STEAM disciplines (Glancy & Moore, 2013). Figure 5.1 further extends the LTM paradigm and the STEM translation (STL) model as a variation of the LTM emphasizing the shared mathematical framework and with non-STEM domains relevant to each of the primary STEM components as represented by the individual and concentric circles, respectively. The diagram represents a new way of thinking about the interrelationship between STEM and non-STEM components through a common mathematical framework.

The framework shown in Figure 5.1, which was derived from the literature and the data gathered in the study, sets the stage for a new Glaserian or Straussian grounded theory on STEM pedagogy (Charmaz, 2006; Glaser, 1995; Strauss & Corbin, 1994; Van Niekerk & Roode, 2009). The conceptual STEAM translation pyramid is rooted in information systems and software engineering because it is envisioned to be embedded within an overarching artificial intelligence expert system framework—a revolutionary approach to automated content analysis that can be applied to virtually any STEM learning context.

Multimodal content delivery is also an important device for STEM learning and engagement using the model of Figure 5.1. Multimodal content delivery must exploit visual, tactile, and experiential learning for real-world problem contexts, along with PBL protocols for students to develop the soft skills useful in STEM for effective communication and social group interaction. Such techniques help to stimulate creative independent and team learning and critical thinking to deepen STEM engagement. The finding and its implications corroborate the literature on the advantages of using
technology-based, multimedia, and multimodal learning environments (Bruce-Davis et al., 2014; Capraro et al., 2016; Connors-Kellgren et al., 2016; Proudfoot & Kebritchi, 2017).

![Figure 5.1](http://docs.lib.purdue.edu/enewp/1)

*Figure 5.1. The STEAM translation pyramid (with math and non-STEM at the center) as the combination of the individual disciplines along with the translations that connect them. Adapted from “Theoretical Foundations for Effective STEM Learning Environments,” by A. W. Glancy and T. J. Moore, 2013. In School of Engineering Education Working Papers. Paper 1 (p. 18). http://docs.lib.purdue.edu/enewp/1

The introduction of non-STEM (arts and humanities) subjects as part of a progressive STEM curriculum provides for rich, impactful learning contexts. However, music was not explicitly identified as a viable STEM engagement device despite the research findings in Chapter 2, which was an unanticipated finding. Specifically, the finding and its implication contrast with the perspectives of Daugherty (2013), Gordon et al. (2018), Grant and Patterson (2016), Hummell (2014), Moyer et al. (2018), Payton et
al. (2017), Slater et al. (2017), Tobias (2014), Wu et al. (2015), and Wynn and Harris (2013) on the eclectic ways people engage with music through technology and math including performance art in the context of STEM learning. Music has not been rigorously used or tested in any type of STEM intervention opening an avenue of possible research in the future.

The failure to prepare the high school STEM graduates for the rigors of the college STEM experience could cause them to switch to a non-STEM major or drop out of college altogether. The hope is to propel them into STEM as a college major or as a career choice by preparing them academically and emotionally to not fear challenge and embrace and manage failure as a learning experience. From the viewpoint of STEM persistence, it is incumbent on the educators and institution to enable informed choice by balancing support of both college/professional and vocational/trade STEM opportunities. The implications of STEM marketing and messaging are discussed in the next section.

**Finding 4: STEM marketing and messaging—gauging the message properly to recruit and retain STEM interest.** A major gap arises from STEM outreach that fails to build on students’ early exposure to STEM; in the students’ view, the high school programs lack multidisciplinary diversity and do not resonate well with their interests or expectations compared to their earlier experiences. On the other hand, the educators see inconsistencies in “capturing” STEM interest at a young age and maintaining the continuity of STEM programs prior to and during the high school years. Forcing the STEM agenda rather than nurturing STEM engagement at a young age is detrimental. Failing to expand opportunities that match specific interests or needs in support of STEM career pursuits and disempowering informed freedom of choice are equally harmful to
engagement. The students see a need to step in and expand the advertising of STEM programs to elementary/middle school grades via personal visits and presentations. Such outreach would be a way for the STEM students to convey their individual experiences and knowledge gained, friendships formed, and the many fun group activities and learning opportunities to proactively close the gap.

The forceful STEM messaging, which puts college-based careers way ahead of vocational/trade-based pursuits, devalues the message; the marketing and outreach fail to promote college/professional and vocational/trade career pathways in a balanced way. The imbalance limits one’s choices and fails to meet outside expectations in terms of traditional STEM career fulfillment. The STEM outreach is not well-defined and lacks cross-disciplinary associations, calling into question the effectiveness of today’s outreach tactics on long-term engagement. The message clearly states a college STEM degree is preferred over a technical vocational/trades certificate, which is an over-hyped and highly biased tactic. Over-propagandizing the STEM message could certainly disengage STEM interest because it diminishes choice and dampens self-interests or personal pursuits. The STEM outward messaging is confusing and conflicted, and where the goals of recruitment are ill-defined vis-a-vis enhancing workforce preparedness. The STEM messaging must be changed for better targeting and improved outcomes.

Hyping STEM as a panacea for workforce preparedness, but where STEM education is not consistently defined and the strategies for developing and implementing high-impact STEM programs are uncertain, adds to the disengagement effect. The messaging is vague and open to interpretation, leading to a wide array of programs that on one hand, are beneficial in terms of diversity, but on the other hand, are confusing and
inconsistent with varied expected outcomes. Again, it comes down to defining what
STEM means and why it is important for workforce preparedness and global leadership.

A combination of poor marketing and advertising of STEM offerings and the
myriad non-STEM options and conflicting schedules exacerbate the problem and deny
valuable learning opportunities for the students. The marketing, structuring, and
scheduling of STEM classes and electives are forcing the students to choose from an
overabundance of options that become confusing or overwhelming. Frustration and
discouragement arise by failing to crystallize the STEM message and by conducting an
ineffective STEM marketing/advertising campaign that works against raising awareness.
The students become less aware and consequently less empowered to make independent,
informed academic and professional career choices best suited to their interests, thus
contributing to the gap. The STEM publicity struggles because although STEM is highly
touted often at the exclusion of all else, the published materials fail to raise its visibility
to the same level of importance. The messaging is muddled and lacks targeted focus.

Whereas the students focus is on the outward messaging used to recruit students
into the STEM program, the teachers’ focus is more on the inward messaging to students
once they are “captured” into the program. The STEM marketing strategies and inward
messaging often foster misconceptions about the program that can set STEM students up
for failure upon entering college or the workforce. The high school students—a
vulnerable group—may be unsure of their college/career path and could have been
encouraged or pressured into pursuing STEM, and where non-STEM pursuits are
frowned upon. In other words, the graduating students are not consistently prepared for
or certain of their postgraduation plans and pursuits, thus contributing to the gap. The
problem reflects a lack of reliable school career guidance. The messaging neglects to balance multiple factors that influence career decisions such as job demand, advancement opportunities, and so on rather than solely on personal interests and salary considerations.

Another implication of current STEM marketing is concerned with the specific nature of the message. The barrage of conflicting messages such as, “STEM is harder than other subjects,” or “grades are key,” or promulgating misconceptions that STEM is reserved for the elite, or advertising STEM to only those with the “right credentials,” may “flip the switch” in engagement. The switch often occurs between high school graduation and the first year of college.

The STEM marketing and outreach campaign is not openly inclusive of disadvantaged, underserved, or underrepresented groups and fails to dispel elitist attitudes and socioeconomic and sociocultural stereotypes. The forced marketing blitz to fill artificial quotas for females in STEM is having a polarizing effect on STEM attitudes, and the resultant pressure on females is backfiring by discouraging them from naturally and freely choosing fields or professions that they want to pursue—failing to build on one’s passion, talent, fit, and choice regardless of gender. Doubt is cast by questioning females about their choices when it comes to STEM versus non-STEM fields or pursuits which serves to widen the gap.

The STEM marketing, in the context of social justice, fails to address concerns over gender parity, equity, equal opportunity for high-paying jobs, reward and fulfillment, financial security, and personal happiness. The marketing fails to promote STEM as an enabler for competitive skills development in fields that embody social justice and social equality touchpoints. The STEM marketing also fails to address
technology’s role in society for improved quality of life; opportunities and incentives for underserved groups; philanthropy and humanitarian needs; contributions to job growth and societal financial health; and corporate or other organizational outreach. Concerns exist over perpetuating barriers to STEM entry via mixed messaging on certain STEM fields being more competitive than others when combined with socioeconomic and sociocultural factors or indicators. The STEM landscape becomes fog shrouded. The implications of organizational and individual inertia to STEM curriculum change are discussed in the next section.

**Finding 5: Organizational and individual factors—the need for building organizational and individual capacity to establish a viable STEM support system.**

An earlier theme resurfaced, that of organizational inability or unwillingness to build and nurture STEM capacity beyond the limits imposed by state curriculum standards by failing to employ novel STEM pedagogical best practices. The theme points to the “politics” and “economics” of instituting an increased capacity to nurture meaningful and impactful STEM programs. The “systemic” multiorganization inertia works against implementing a near-term, progressive STEM strategy and the high school fails to keep pace due to protracted inaction and a reticence to change. Several additional concerns contribute to the gap that include (a) the lack of implementing STEM pedagogy best practices, (b) a lack of informed school counseling, and (c) systemic institutional practices with social injustice implications.

STEM disengagement is a direct result of the academic institution’s failure to proactively implement proven best practices beyond progressive, multidisciplinary pedagogy. The best practices here refer to operating at deeper levels for mutual trust
building, assessing lesson effectiveness and course correcting as necessary, active student outreach, and providing a nurturing support environment. The finding and its implications corroborate the literature on the importance of fostering self-efficacy and confidence, teacher-student interactions, trust in educators, teachers who inspire and motivate students, and educator and institutional scaffolding (Belland et al., 2015; Fan & Yu, 2017; Jackson et al., 2014; Mativo et al., 2013; Whalen & Shelley, 2010; Wilson et al., 2015). The lack of prepared and informed school counseling that is supposed to offer helpful guidance on the realities of STEM opportunities contributes to the dilemma. The failure to dispense authentic, informed guidance to students about STEM opportunities and not enabling them to autonomously make choices tempered by expert guidance is a major detractor to STEM engagement and contributes significantly to the gap. Career development strategies often focus more on salary/compensation or economic incentives and less on “life’s realities.” A shortfall exists by failing to balance other vital factors such as personal or aspirational interests, self-efficacy, self-improvement, advancement potential, market demand and the willingness to “invest” in the process, and positive social contributions.

Several factors contribute to the issue of ensuring complete, informed, and reliable academic and career guidance. The factors include (a) the lack of direction given to teachers, (b) the sporadic coordination between the administration and teachers regarding counseling goals and expected outcomes, (c) the myriad electives or class offerings, and (d) other distractions that together create a confusing STEM pedagogical landscape. Perhaps the most critical factor is the changing role of school counselors in recent years. According to the students and teachers, the school counselors are
preoccupied with managing students’ social-emotional and behavioral issues daily and dispensing informed career guidance has become secondary or altogether absent; instead, career guidance is now routinely delivered by educators, but the teachers are not always prepared to deliver counseling and concerns arise over the students who are outside the STEM teachers’ spheres of influence. Again, this was an unanticipated finding with clear negative implications as far as the students are concerned.

The combined lack of informed, engaged, and reliable career counselors dedicated to the task, and the absence of dependable and insightful STEM career guidance for students are significant STEM gap contributors, that was independently corroborated by both the students and educators, forming one of the major findings of the present study. The failure to ensure continuity in teacher/counselor/mentor support systems and informed guidance, and the failure to prepare students for college and the rigors of multidisciplinary group STEM learning in college, causes disillusionment and gives students pause about continuing, switching majors, or dropping out of college. A related career counseling issue is the failure to recalibrate the notion of STEM as being inclusive of technical vocational jobs or trade opportunities and enabling choice by weighing cultural values. Some students who are interested in STEM trades feel disenfranchised from mainstream STEM opportunities.

Indeed, the lack of dedicated, informed counseling and the mixed messaging on STEM sets up yet another barrier that contributes to the gap. First, misconceptions are often socialized regarding the rigors and demands of the STEM fields compared to the perceived “lesser” demands of the non-STEM fields. Second, the students are swayed by messages on the higher benefit-to-risk ratios for non-STEM majors in terms of
competitive salaries and benefits, reduced commitment and scholastic intensity, high job demand, and lower stress making it attractive for them to abandon any notion of a STEM career. The considerations over risk versus reward, expectations and demands, stress or anxiety, and negative outcomes are especially important in the case of students with low STEM affinity who are funneled into the STEM pipeline.

At the same time, the high school is expected to produce “master class” STEM scholars to ready them for college, but the students are not always well-positioned in the pipeline. The teachers claim that the responsibility of producing master-level STEM students should be shifted to the colleges, although the high school agrees it should continue to deliver reliable college preparation curricula. In their view, the higher education institutions fail to proactively ensure that students are successful in STEM or have viable alternatives. The lessons learned can be used to advise high school administrators of the factors contributing to disengagement and how to mitigate them.

Whereas the students’ view of institutional “systemic” problems reflects the lack of a progressive STEM agenda, the educator’s view on the multiple “systemic” issues and institutional shortcomings are directed at inherent system biases. They referred to biases that favor (or deny) STEM educational opportunities based on privilege, class, wealth, and power—a social injustice context. They saw the lack of action or not taking more aggressive steps toward change as a means of widening the STEM gap and contributing to middle class erosion as a socioeconomic issue.

Several other recurring themes contributing to the gap resurface relating to social justice. The themes include (a) perpetuating stereotypical beliefs on the expected roles of males and females or underrepresented groups, (b) failing to expose females to STEM
content at a young age, and (c) STEM marketing strategies that limit or disempower females in making their own choices. Additionally, negative peer response to pipelining females toward STEM knowing that it is a male-dominated and competitive field can daunt the pursuit and contribute to widening the gap. However, some females feel as though they are being coerced into STEM without truly understanding the underlying motives for pursuing STEM. They would rather take charge of the decision to split off into STEM and/or non-STEM classes or to seek a customized program that appeals to their specific interests. Although not endemic to ESM High School, limiting choice on the matter in this way contributes to an erosion of STEM interest.

Other important factors contributing to the gap range from family values on STEM higher education to improving secondary school STEM educational policies and practices to enable a better STEM experience after high school. For instance, a lack of positive family support and peer encouragement can affect one’s decision to pursue a STEM field, but it can be a double-edged sword. As stated previously, peer pressure can work against STEM engagement for a variety of reasons. Also, families motivated by economic incentives can drive their children to achieve good grades at any cost to qualify for STEM college scholarships for the purpose of reducing their financial burdens; however, students who are academically unprepared, uncertain, or perhaps disillusioned by STEM in college may switch majors or drop out, hence contributing to STEM attrition. Similarly, financial incentives in non-STEM fields of study can erode students’ interests in STEM fields. The ongoing tensions must give at some point and often contribute to STEM attrition in the end. The implication is that financial considerations
alone are insufficient to make informed decisions on pursuing STEM and indirectly contribute to the gap, keeping in mind that STEM is not for everyone.

The educators are more fearful of promulgating STEM *elitism*—a populist view where STEM is reserved and “deserved” only for those who meet certain requirements. Higher education itself either intentionally or inadvertently promotes an image of *elitism* and creates a culture of *inequity* that adds to disenfranchisement. The concern points back to the idea of STEM *democratization*. In this context, STEM options for 2- or 4-year colleges, vocational trades, scholarships, internships, job market and timelines, and associated risks/benefits should be considered on an equal footing. The implication is that a STEM pursuit is not restricted to receiving a 4-year degree in a STEM field of study as a minimum. In the educators’ view, the academic system fails to cultivate a “unicorn” mindset—a workforce issue—by not forging stronger intersections between the science/technology and art/design domains—the implication being that people are more naturally *STEAM creatures* and less *STEM creatures*.

Additional gap contributors and implications on STEM engagement and persistence include the failure to connect the high school STEM programs with industry and the business workplace; failing to increase the number of internships, corporate scholarships, and college credits to resonant with STEM students’ fields of interest; failure to adapt educator skills across multiple subject areas to help shape the new STEM pedagogical landscape; and not recruiting industry experts to provide practical STEM training experience to inspire and motivate students. ESM High School is on the right path for increasing STEM engagement, but improvements are needed regarding the STEM curriculum and the policies and procedures that address the above considerations.
Although progress has been made, it has been slow to arrive and the school in many respects is behind on meeting a true, progressive, and impactful STEAM agenda. ESM High School must further shift its focus on student-career success in STEM in view of the above barriers and gaps. STEM engagement suffers if the student encouragement towards STEM is weak or sporadic.

**Finding 6: Social justice detractors—Recognizing and mitigating socioeconomic barriers and sociocultural disparities.** A main contributor to the STEM gap is failing to recognize the larger socioeconomic barriers and sociocultural disparities that underserved or underrepresented groups experience in accessing programs for building STEM affinity. Such groups continue to face a greater number of class and race issues in academia and careers that outweighs gender-bias alone. The predominant socioeconomic and sociocultural factors and their impact on the STEM gap are tied to federal and state legislation that limits or is devoid of financial or other incentives to assist them and mitigate their plight.

The Smithsonian Science Education Center (2020) reported that minorities are significantly underrepresented in STEM fields—the implication being that minorities lack the necessary qualifications to compete for STEM-related jobs, which are not only more plentiful but also better paying than non-STEM jobs in many cases by 12% to as high as 30% across all education levels. Recall that according to Lazio and Ford (2019), the U.S. Department of Labor reported in 2017 that the national average wage for all STEM occupations was $87,570—nearly twice that of all non-STEM professions.

Federal policies particularly mandate that scientific research and technology companies, especially those doing U.S. national defense work, meet hiring quotas across
gender, race/ethnicity, and other socioeconomic and sociocultural demographic criteria. The policy creates conditions that could lead to the hiring of unqualified candidates just to fill quotas that could exacerbate workforce tensions—an imbalance in workforce supply and demand of certain types of skilled labor that are difficult to fill—rather than hiring based on talent and capability, potentially widening the gap. The policy is ill-conceived and prone to failure because it often neglects the scientific and the labor force data needed to launch a truly informed campaign albeit, the policies are allegedly in support of satisfying equal opportunity goals.

The implication here is that the gap expands without a resident, organizational support system in place to nurture the desired STEM skill sets and extend the ecosystem of opportunities for all social groups. Failing to democratize STEM learning by not mitigating unfair practices and applying mandates that favor one demographic over another, regardless of gender or socioeconomic or sociocultural status, can contribute to attrition and a widening of the gap. Additionally, many technology companies fail to use regional labor data effectively to devise active STEM outreach and engagement campaigns to maximize recruitment outcomes; an ill-advised campaign that does not tap into or appeal to local or regional labor pools can conceivably contribute to a widening of the STEM gap. Such data can be used to step up or customize outreach as necessary, to offer internships, engineering scholarships, and financial aid/incentives especially for disadvantaged or underserved STEM-oriented individuals.

Furthermore, perpetuating gender-bias stereotypes and failing to cultivate the associations between strength and empowerment and being a female in STEM only worsens the gap. Not exposing females to STEM at a young age to establish a foundation
to build upon in their later years is a truly risky strategy, along with questioning or challenging their career decisions. Females should take a stance on the growth in the number of women entering the STEM fields and who break through the “glass ceiling” in response to disparity issues to show that change is in process to narrow the gap. Although STEM fields are male dominated, failure to recognize that the reasons for the STEM gaps supersede the issue of gender bias and encompass socioeconomic or sociocultural factors can result in a misguided STEM recruitment campaign with diminishing returns. The next section turns attention to the relevant implications of implementing progressive STEM programs based on the findings of the study for urban, inner-city schools.

**Implications of progressive STEM education for urban, inner-city schools.**

The practical rollout and delivery of progressive STEM programs and the realization of successful outcomes for large, urban, inner-city schools present major challenges. *Rapid workforce scaling*—managing or sustaining the supply and demand of skilled labor has been problematic in the case of STEM. Workforce scaling depends on number of successful graduates from secondary and higher education institutions who are STEM-disposed. Attention is placed on primary and secondary inner-city schools in large urban areas because they represent a significant pool of potential STEM workforce candidates. The social justice imperative is to maximize positive outcomes for disadvantaged students in large, urban, inner-city schools and provide for equity and equal opportunity.

The imperative reflects the inherent, real-world disadvantages that urban, inner city students face, especially children of color, that literally threaten their survival and their families’ daily ability to make ends meet. The socioeconomic and sociocultural
barriers are often well beyond their control. The disadvantages, as the present study revealed, unfairly hamper exposure to progressive STEM programs that could lead to positive, life-changing outcomes. To maximize positive outcomes for students in urban, inner-city schools and upwardly scale STEM workforce projections, a *head-start* marketing and financial assistance plan must be unrolled aimed at disadvantaged children starting as early as preschool age. Urban, inner-city children who are most socioeconomically challenged and at high risk will gain much and lose little by having equitable access to programs that can produce a high workforce return on a modest investment in STEM.

The plan’s intent is to curate STEM affinity at a young age and continuously nurture that affinity by making progressive STEM learning programs more readily available and accessible to urban, inner-city children. The plan’s premise is derived in part from the thriving child model which states that learning outcomes for children are more likely to be positive when they have access to high-quality, meaningful education at an early age, their families are invested and engaged in their learning future, and education draws on the local community’s cultures and history (Reid, 2012). Viewed as an independent variable, affinity can be used to create a positive “tension” in which building STEM affinity (push) is met by industry/workforce demand (pull) to modulate (narrow) the STEM gap. Again, children in inner-city schools in large metropolitan areas represent a significant pool of potential STEM candidates who would be given fair and open opportunities to be exposed to progressive STEM learning and earn rewarding careers.
The goal is to ensure a positive impact and successful workforce outcomes for at least the next 20 years. The general strategy will further help curb a dwindling STEM workforce, close the divide between privileged and disadvantaged social classes, reduce the disparity and divergence in workforce trends, and mitigate the STEM pipeline leakage. The plan will require school districts, state education boards, politicians, and urban community stakeholders to support seed-funded programs towards achieving self-sustainment through corporate matching, public contributions, and private fund raising.

Another consideration is risk aversion. A progressive STEM program, such as the one based on the STEAM translation pyramid, can be considered too “disruptive” technically and a financial risk with unknown or unanticipated outcomes. The plan to propose such a program could face roadblocks to adoption by urban, inner-city school districts and other stakeholders for these or other reasons. To address risk, cost-benefit and business case analyses should be conducted to quantify the technical, programmatic, and budget/cost items and propose risk mitigation strategies. Additionally, prior case studies of evidence-based STEM interventions can be referenced to provide ground truth for implementing cost-effective, wide-range programs in urban schools.

For instance, recall Capraro et al. (2016) in a longitudinal, mixed-methods study investigated the impact of urban secondary school STEM project-based learning on student achievement and teacher STEM professional development. The study collected observational data along with focus group interviews over a 3-year period on three high schools within an independent urban district where approximately 83% of the students were classified as low-income or poor. The students were predominantly Black (34.9%) and Hispanic (50.9%). Capraro et al. provided compelling evidence of PBL’s efficacy in
improving student STEM achievement for high-fidelity interventions in urban classrooms. Bruce-Davis et al. (2014) also cited PBL as an effective STEM engagement protocol, thus supporting the claims of Capraro et al. in the urban PBL study. Their results were also consistent with the findings of Brown (2012) and Springer and Stanne (1999) on the benefits of active, small-group collaborative project learning. However, the study by Kezar and Gehrke (2017) only agreed with the findings of Capraro et al. on the beneficial impacts of delivering creative and stimulating instructional content.

Also recall Bonny et al. (2017) postulated a possible link between hip hop dancing and STEM learning and sociocognitive abilities in young adults attending urban schools. The study by Bonny et al. suggests that the fine arts, viewed through the lens of urban hip-hop dance art and culture, could be an effective STEM engagement device and enhance sociocognitive skills through youth-based collaborative group activities. They concluded that hip hop dancing could effectively augment the STEM learning experience. The findings and conclusions by Bonny et al. paralleled those of Hutto, et al. (2015), Stieff and Uttal (2015), von Károlyi (2013), White et al. (2012), and Gold et al. (2018) on the relationships between spatial abilities, mental rotation, and overall STEM achievement. The lessons learned from these and other studies can be revisited or replicated to inform the rollout of effective strategies for urban, inner-city schools in large metropolitan cities to address STEM workforce scaling.

Collateral concerns: political social messaging. Lastly, STEM should be exploited as a tool to “remedy” certain ill-posed political messaging that “lacks the science” to preclude disenfranchising social groups. The lack of policy reforms to restructure STEM education must be overcome before true change can take place and the
benefits realized (Ernst et al., 2018; Kezar and Gehrke, 2017). Efforts must be undertaken to advise and inform federal and state political leaders on STEM education reforms that could benefit underserved and underrepresented groups let alone the school system at large. The next section will discuss the limitations of the study including the weaknesses or problems that may have impacted the results.

**Limitations**

Three *moderate* limitations were identified in the present study. The first limitation was that the educator focus groups, although originally aimed at STEM teachers, ended up drawing on a mix of STEM and non-STEM educators. Nonetheless, each of the educator focus groups was predominantly composed of STEM teachers. The non-STEM educators were directly involved with or indirectly part of the Spartan Academy STEM Program via elective classes, so they had keen insights into many of the relevant STEM and STEAM retention issues or concerns. Several of the STEM teachers either were unavailable for the study due to schedule conflicts or other constraints, and the number of STEM teachers was somewhat limited for the purposes of the study. In fact, most of the core ESM High School STEM teachers participated in the study providing for a reasonable, minimum number of participants in accordance with the original goals case study design methodology.

However, the above limitation had a serendipitous outcome. The educator focus groups were aimed at STEM educators and it was originally thought that having non-STEM educator perspectives could potentially dilute the findings. On the other hand, obtaining diverse perspectives from non-STEM educators either directly or indirectly involved in ESM High School’s STEM program provided for a diverse set of viewpoints
which turned a limitation into a benefit. Notwithstanding, additional time would have been advantageous to explore some of the themes expressed or that emerged which would have further benefitted the study. The latter point raises the second limitation which was the timing and schedule of the study.

Whereas the timing of the study was intended by design to coincide with the last several months of the spring term approaching high school senior graduation, its start was delayed for several reasons. The reasons included limited participant availability, Regents examination conflicts, and other schedule constraints that preempted a timely commencement of the study for a critical mass of participants. In effect, information gathering was somewhat compressed based on a limited population of participants over a restricted schedule rife with conflicts and other constraints and the need for multiple rescheduling of the focus groups forcing the conduct of multiple focus groups as described in the study. The timing problem was exacerbated by having to conduct focus group sessions across two terms namely, the end of the 2019 spring through summer terms and into the 2019-2020 fall/winter term, during which the Coronavirus (COVID-19) struck the nation limiting any further follow-up or closure activities. Nevertheless, a reasonable sample of participants was achieved given the disjointed timeframe of the study that met or exceeded the minimum requirements of the proposed case study methodology. The observation points to the third limitation of the study—the limited number of focus group students.

Originally thought advantageous and meaningful to the data gathering process, the study was designed to focus on STEM students who were at least 18 years of age and on the verge of graduating. However, a two-fold barrier was faced in addition to the
schedule limitations that made it difficult to assemble eligible students for the focus
groups at an appointed time. The small number of eligible students presented itself as the
third limitation. Consequently, three separate student focus groups had to be conducted
to obtain a reasonable and minimum population using purposeful sampling. In other
words, it would have been more beneficial and efficient to hold no more than two focus
groups each with a greater number of participants to facilitate more interactive
discussions, but this was prevented by the scheduling and availability issues. The study
was expanded with the approval of the IRB to entertain feedback from students 17 years
of age but was discounted in the final analysis. At the time, most of the study had been
completed and it was deemed sufficient data was gathered based on the 18+ year old
students to warrant final data reduction and analysis and the conclusion of the study.

Despite the above limitations, a gap was found in the literature regarding studies
on STEM engagement, retention, and persistence conducted with STEM educators and
high school seniors on the verge of graduation. Although the present study and its results
were confined to the ESM High School STEM program experience, many of the findings
pointed to a larger gap issue leading to a series of recommendations as discussed in the
next section. The recommendations include preliminary actions plans for secondary and
higher education, state education, and legislative bodies. Future open areas of research
are also identified next.

**Recommendations**

The study’s findings led to several recommended actions for higher education
institutions and faculty, secondary education administrative and instructional leaders,
state education legislative bodies, and future research. The sections that follow provide
three recommendations for higher education administrative leaders, six recommendations for secondary education administrators and instructional leaders, one main recommendation for legislative bodies, and four recommendations for future research. Leadership and organizational social change and transformational theories provide the basis for implementing the recommendations to realize paradigm shifts that would benefit STEM pedagogical reform (Bolman & Deal, 2017; Collins, 2001; Kouzes & Posner, 2012; Lewin & Grabbe, 1945; Northouse, 2013). The goal is to reimagine strategies for STEM implementing pedagogical policy reforms. The next section addresses the first recommendation for higher education faculty and institutions and identifies the ramifications of leadership and organizational social change to achieve the desired outcomes.

Actions for departments of education at institutions of higher learning – galvanizing efforts towards progressive STEM preparedness training. An important leadership imperative emerges regarding the development and delivery of future high school STEM curricula and counseling that focuses attention on the role of higher education institutions. The imperative is to closely examine the bridge between STEM and the fine arts for preservice teacher preparedness and administrator restructuring to foster programs that take advantage of the power of integrated, interdisciplinary learning as a paradigm shift to close STEM engagement/persistence gaps. The imperative is also to ensure the preservice school counselors are properly trained to provide informed and reliable STEM college/career guidance.

In particular, the approach would draw on the perspectives of educational leaders in college/university teacher and counselor preparation for high schools. The goal is to
improve preservice teacher and counselor preparedness at institutions of higher education to raise awareness of progressive, in-service STEM pedagogical strategies and the need for informed counseling at the secondary school level. However, a tension exists between secondary schools and higher education institutions regarding STEM awareness due to several factors. The factors include the ongoing pressures of high-stakes state testing and scripted programs; the use of test scores as the key measure of achievement tied to teacher assessments; a lack of endorsement of novel STEM practices; a resistance to STEM reforms; and a lack of informed school counseling regarding the realities of STEM fields and careers.

The tension raises the following questions: “What STEM best practices should be implemented and how?” and “How can high schools provide reliable and meaningful STEM college/career guidance? An additional question is, “Should high school teachers be responsible for producing “STEM master class students” or is it more important to focus on knowledge discovery, information sharing, and enabling the students to exploit every opportunity to succeed to the best of their abilities?” The study resulted in two key recommendations for preservice STEM faculty and school counselor preparation programs in colleges and universities and one recommendation for higher education administrators.

The first implication is for policy makers in STEM and arts teacher education at institutions of higher learning to consider preservice STEAM curriculum and field experiences (Peppler & Wohlwend, 2018). The preservice teachers in training must be inculcated in understanding the need for curriculum reform and the importance of rolling out transformative, progressive STEM programs that selectively tap into the fine arts and
efface siloed learning models. Teacher training programs help shape the pedagogical framework for incoming, in-service teachers. Currently, a lack of flexibility exists for teachers to implement progressive STEM learning strategies in the classroom; undergraduate teacher training is equally inflexible at enabling progressive STEM learning classes. It is important to imbue preservice teachers with new ideas that they can implement and to lead brainstorming activities at the in-service, secondary school level to change the future of the STEM pedagogic landscape. The implication here is to install agents of change in secondary institutions who have the knowledge, insight, entrepreneurial mindset, and capacity to roll out progressive curricula and programs.

A progressive agenda is viewed through the lenses of integrated, multidisciplinary, content-diverse, interactive, immersive, inquiry-based, and experiential learning that is non-siloed and non-classroom-confined, and that emphasize real-life problem-solving. The agenda is consistent with implementing active, constructivist problem-based learning that taps into real-world applications (Smith, Douglas, & Cox, 2009). The progressive curricula and programs must have traction, consistency, and reliability for long-lasting effect and points to the notion of cultivating “unicorns”—individuals who embody the knowledge and skills across multiple STEM and non-STEM disciplines.

The current academic system fails to cultivate a unicorn mindset by not effectively or consistently forging stronger intersections between the science/technology and art/design domains using real-life applications and recognizing that people are naturally STEAM creatures as opposed to STEM creatures. The failure to address this fact translates into a workforce issue where students are unsure of their academic STEM
path and their career aspirations because it is less about a monolithic path to success (trunk model) and more about a path that offers flexibility, options, and a diversity of opportunities (branch model). Today’s STEM workforce depends on individuals with more diverse skill sets, agility, flexibility, and a capacity to focus their core skills and abilities, as necessary. Therefore, the imperative is to ensure that preservice teachers are made aware of the importance of cultivating a unicorn mindset to meet the STEM workforce demand—the ultimate objective. The knowledge and insights gained could potentially assist incoming teachers to establish a more natural and conducive learning system with enhanced engagement outcomes.

The STEAM translation pyramid of Figure 5.1 is one method of addressing preservice teacher preparedness by integrating progressive content into the current STEM curriculum. The findings on brain-based learning theory, environments, and interventions can also be used to inform preservice teacher preparation programs and in-service teaching practice in how to optimally framework STEM curricula and bolster strategies for successful outcomes (DiTullio, 2018). The vast majority of faculty and students in the focus groups were familiar with the latest research and trials for incorporating integrated, multidisciplinary concepts into foundational STEM classes. A minority of the educator and student participants were less in favor of introducing non-STEM content unless there were good reasons to do so.

Hence, the first recommendation is for the departments of education in higher education institutions to reevaluate their existing preservice teacher preparedness programs and to consider the inclusion of a STEAM translation pyramid approach as a framework for a revised curriculum rather than instituting a separate course. Recall that
the STEAM translation pyramid is derived from the LTM theory (Lesh & Doerr, 2003; Lesh & Harel, 2003). Indeed, other programs and strategies could be considered such as brain learning or other approaches. Additionally, the curriculum would be reinforced to include increased “soft skills” content to ensure that preservice teachers develop sound communications skills to effectively convey academic and backup career guidance to students in a reliable and dependable way.

The faculty who participated in the focus groups felt that in principle the preservice teacher preparedness programs could be reevaluated and modified to include new content to drive reform because there are natural alignments across the STEM and certain non-STEM disciplines; however, the state education and legislative bureaucratic processes to enact such change are expected to be challenging. Eventually though, a tipping point is expected where reforms will be more readily adopted in the face of a continually eroding STEM workforce, in view of the international test scores and statistics on U.S. STEM proficiencies, and an outpacing in technical innovation by other nations. This leads to the second recommendation regarding preservice school counselor preparedness programs.

The second recommendation is for the departments of education in higher education institutions to reevaluate their existing preservice school counselor preparedness programs and consider the inclusion of revised college/career awareness content aimed at STEM field placements. The framework for a revised curriculum would preclude the need for instituting a separate course and would focus on STEM counseling models that ensure informed guidance on STEM college/career pathways and that exploit
a cultural values mindset. The strategy would exploit the theme of incorporating career awareness education with respect to STEM (Reiss & Mujtaba, 2017).

The revised counseling preparedness curriculum would address the “life realities” of pursuing a STEM college or career path by weighing salary and self-interests against other external career trajectory factors that influence one’s decisions to follow a STEM path. The factors include risk versus reward, job market, expectations and demands, managing stress or anxiety, and the ability to deal with negative outcomes especially for students with low STEM affinity who are pipelined into STEM fields. A complementary counseling strategy is to exploit self-motivational theories to stimulate one’s creative potential and entrepreneurial outlook and to think beyond salary and pure self-interests (Gambrel & Cianci, 2003; Maslow, 1965; Paul, Niehoff, & Turnley, 2000). Again, the curriculum would be reinforced to include more “soft skills” content to ensure that preservice counselors develop sound communications skills to effectively convey primary academic and career guidance to students reliably and dependably.

The students and faculty who participated in the focus groups were nearly unanimous in expressing concerns over the changing role of high school counselors and the shift of career counseling responsibilities to the educators. The faculty participants felt that in principle, the preservice counselor preparedness programs could be reevaluated and modified to include new STEM career content to drive transformation and recalibrate the role of the counselor. The school counselors should continue to advise on academic matters. However, they should be more thoroughly trained to prioritize their duties amidst competing needs to avoid diluting career counseling capacity and provide reliable and dependable guidance on core versus elective course
options. They should also be trained to recognize STEM affinity cues and administer guidance considering higher education expectations or workforce demands. The considerations lead to the third recommendation pertaining to higher education administration and the management of expectations regarding STEM readiness.

Clearly, much of the responsibility to assure that a student succeeds and thrives in STEM beyond high school must reside with the colleges and universities. Therefore, the third recommendation is for higher education administrators to accept a greater share of the role and responsibility for raising students STEM proficiencies to be commensurate with the college/university curriculum rather than expect the high schools to consistently produce students having master class STEM proficiencies. A recommended paradigm shift starts by not over-dwelling on rigor at the high school level to meet the testing standards and putting scholastic master class achievements on the shoulders of the higher education institutions, while at the same time delivering reliable college preparatory STEM content in high school. Most of the participants in the educator focus groups felt that a better understanding between secondary schools and higher education institutions could be achieved via the intercession the state education boards. The solution to the problem is closely tied to reforming the high stakes testing model that currently exists. The additional recommendations to secondary school administrators, STEM faculty, and instructional leaders on that front is discussed next.

Actions for secondary school administrators, STEM faculty, and instructional leaders – galvanizing efforts toward progressive STEM pedagogy. The study brought forth six recommendations for secondary school in-service STEM faculty, instructional leaders, and administrators that are closely tied to the recommendations for
institutions of higher education. It is first recommended that institutional administrators and educational leaders, particularly superintendents, assistant superintendents, high school principals, and assistant principals who administer instruction, lead the reevaluation of extant curricular policies and the application of state Common Core testing standards. Specifically, secondary school administrators and district leaders should appoint a diverse committee of instructional leaders to identify and rank critical reforms and associated milestones and timelines for STEM pedagogical programs. The further implication here is for institutional policy leaders in STEM and arts pedagogy to envision new, transformative tools and classroom environments that can work to narrow the STEM gap (Peppler & Wohlwend, 2018). The plan would be to leverage the STEAM translation pyramid as a possible framework, which establishes a blueprint for incrementally rolling out a progressive STEM (or STEAM) curriculum. Its full implementation would be contingent on the approval and adoption by the New York State Education Board and the Department of Education.

DiTullio (2018) cited a study by Welner (2014) claiming that the current educational accountability approach based on high-stakes state testing and scripted test preparation programs is “counterproductive and unwise” (p. 121). Like DiTullio’s findings, the educators in the present study were enthusiastic about multidisciplinary and cross-curricular (STEM) immersion learning unbounded by scripted programs and that similarly “allowed for choice, creativity, collaboration, and communication” (p. 121); according to DiTullio, a higher degree of student engagement occurs using brain-based strategies, thus reinforcing many of the present study’s earlier reported findings. The existing STEM curriculum and the high-stakes state testing practices should therefore be
reevaluated, and the academic policies and practices should be reformed by introducing a STEAM translation pyramid framework—a variant of the LTM theoretic framework.

The district superintendent or assistant superintendent, in cooperation with the school principal and assistant principal, should lead the reevaluation of the existing STEM curriculum and state testing practices. Using the STEAM translation pyramid, the school districts can identify curricular realignments that match the needs and goals of a progressive STEM learning agenda. The in-service instructional teachers should be relied upon to provide inputs to prioritize or revise parts of the STEM curriculum to include teaching modules that leverage proven STEM pedagogical best practices. Emergent theory together with Lewin’s change model will provide the basic lenses to focus reforms that are beneficial to the committee members and leaders to arrive at a practical solution set (Charmaz, 2008; Lewin & Grabbe, 1945; Wilson, Broughan, & Hillier, 2017).

The “infrastructure” to support an incremental rollout of progressive STEM curriculum reform leads to the second recommendation aimed at creating conducive environments that pave the way for reforms to take root. DiTullio (2018) offered relevant strategies by Caine and Caine (1994) and Berliner (2011) that provide a way forward, drawing on the principles of relaxed alertness and orchestrated immersion in the context of curriculum rollout. DiTullio stated,

Teachers need to create a classroom environment that has high-challenge, low threat, and allows students to engage in rich, complex learning experiences. In the case of frequent high-stakes testing, there is a narrowing of the curriculum and an increase in the use of rigid, scripted programs. (p. 121)
To address the infrastructure needs, it is further recommended that secondary school and district leaders examine how academic facilities and physical spaces inside and outside the classroom can be optimally configured using the lens of the STEAM translation pyramid. DiTullio (2018) suggested that elements such as lighting, scents, music, flexible seating, and movement among other measures could be reexamined, in the context of brain-based strategies, which are considered highly complementary to the present study and current recommendation.

The third recommendation is that school districts should sponsor professional development training in progressive STEM learning interventions, best practices, and pitfalls to all teachers and to raise awareness on effective strategies for marketing, advertising, and outreach. The literature and data analysis findings show that putting progressive STEM learning strategies into practice can benefit students’ STEM engagement level, academic performance, and career decisions. Therefore, it is recommended that the STEM teachers implement purposeful lesson plans that are aligned with the goals of progressive STEM learning to enhance engagement, while focusing outreach efforts on students with moderate-to-high STEM disposition.

As part of the third recommendation, the school district leaders, in cooperation with the in-service instructional teachers, should establish a theoretical foundation to launch progressive STEM pedagogy that is aligned with extant curriculum and academic policy. The STEAM translation pyramid could be used as the theoretical foundation to accomplish this. The professional development training for all secondary school administrators and in-service instructional teachers would provide a framework for
understanding the impact of specific progressive STEM learning strategies that the educators can integrate into their lesson plans.

Virtually all the educators who participated in the present case study were familiar with many of the strategies underpinning a progressive STEM learning model. The educators articulated how they had integrated certain strategies into their lesson plans; albeit attempts to trial or pilot certain programs met limited or short-term success. The non-STEM teachers who do not have a working knowledge of progressive STEM learning strategies may find it more difficult to understand and integrate STEM pedagogic reforms into their lesson plans. However, as the present study showed, it was sometimes easier for STEM topics to creep into non-STEM elective classes than it was for non-STEM subjects to be integrated into STEM classes. Nonetheless, STEM and non-STEM educators will have the opportunity under a new foundational framework to encounter strategies and concepts that could be advantageous. Webinars and training seminars can be set up to provide professional development training to raise awareness of novel strategies for lasting impact and measure.

Next, the fourth recommendation is for the school districts to mandate the development of a standard lesson planning framework consistent with the progressive STEM theoretical foundation. Many of the educators who participated in the study alluded to the development of daily or weekly lesson plans. However, the same educators were at odds with lesson plans that fully conformed to the rigid state standards on content delivery. When veering from the plan, the educators felt they had missed essential core content. The purpose of the required lesson planning framework is to have a tool that can be used to purposefully incorporate new, progressive STEM learning
content while not compromising essential core content. The STEAM translation pyramid provides a foundation for developing a lesson planning framework that can be used to manage STEM content development and delivery.

The fifth recommendation is aimed at secondary school in-service counselors and again, ties into a prior recommendation at the higher education institutional level. The fifth recommendation is for the secondary school administrators to reexamine their existing in-service school counseling programs and to include revised college/career awareness content aimed at STEM field placements. The framework for a revised counseling program would focus on STEM counseling that ensures informed guidance on STEM college/career pathways and that exploit a cultural values mindset. The strategy would exploit the theme of incorporating career awareness education with respect to STEM (Reiss & Mujtaba, 2017).

The sixth recommendation is for secondary school administrators to provide resident training to in-service counselors. The revised in-service counselor training curriculum would redefine the counselor’s role and raise awareness of the “life realities” of pursuing a STEM college or career path by weighing salary and self-interests against other external career trajectory factors that influence one’s decisions to enter a STEM field. The factors include risk versus reward, job market, expectations and demands, managing stress or anxiety, and the ability to deal with negative outcomes especially for students with low STEM affinity who are pipelined into STEM fields. The training would include awareness of complementary counseling strategy that exploit self-motivational theories to stimulate one’s creative potential and entrepreneurial mindset and to look beyond salary and pure self-interests (Gambrel & Cianci, 2003; Maslow,
1965; Paul, Niehoff, & Turnley, 2000). The revised curriculum, responsibilities, and duties would also cover soft skills development to ensure that in-service counselors effectively convey primary academic and career guidance to students reliably and dependably.

Reiterating, the students and faculty who participated in the focus groups were nearly in full agreement over concerns on the changing role of high school counselors and the shift of career counseling responsibilities to the educators. The faculty participants felt that the in-service counselors should be better prepared regarding the realities of STEM—both professional degree and vocational/trade based—and revert to their original role of providing informed, reliable college/career guidance to students. The school counselors should continue to advise on academic matters but receive training in how to prioritize their duties amidst competing needs to avoid diluting their career counseling capacity and provide for reliable and dependable guidance regarding core versus elective courses. The training should also help counselors to better recognize and manage STEM affinity cues and provide informed counseling considering higher education expectations or workforce demands.

The implications for school districts and secondary education instructional leaders presented in this section leads to a corollary implication. As discussed in Chapter 2, a dearth of evidence exists in the research corpus on progressive STEM programs and curriculum development for enhancing engagement through the lens of artificial intelligence (AI) / knowledge-based (KB) interventions. The use of AI/KB-assisted interventions that are built on a theoretic STEM framework, namely the STEAM translation pyramid, is discussed in the next section.
Reimagining STEM policy reforms—progressive STEM pedagogical interventions using a knowledge-based approach. The study suggests that a system design approach to progressive STEM pedagogic intervention that considers the problem through an AI/KB lens could significantly benefit STEM engagement goals. Figure 5.2 conceptualizes an AI/KB-assisted system denoted as the STEM prism that leverages the STEAM translation pyramid theoretic framework to develop optimized programs and customized curricula that can serve specific institutional needs for expanding STEM engagement. The STEM prism is characterized as a manifold—a topologically closed set of multiple interconnected and interdependent systems—embedded, nested frameworks that are described as follows.

First, the STEAM translation pyramid of Figure 5.1 provides the foundational theoretic framework. Recall that the Pyramid, in principle, provides a mechanism for interconnecting the STEM subjects to each other and integrating selected non-STEM subjects through a common mathematical framework. The Pyramid provides the basis for addressing progressive STEM pedagogical goals and objectives across a range of inputs. For instance, the findings of the present study can be used to derive inputs regarding STEM content and delivery, learning environments, outreach methods, institutional factors, and so forth. The inputs are used to drive the next step of the process. The nested frameworks embedded within the prism construct work with another manifold consisting of three interdependent engines: the multi-objective optimization (MOO) engine, cooperative competition (COOP) engine, and rules of STEM engagement (ROSE) engine.
The combined engines and frameworks create a master AI/KB engine (STEM prism) that can be used to output an optimized set of guidelines for rolling out a customized, progressive STEM program and curriculum. The outputs are quantized along a continuum of desired spectrum outcomes. Conceptually, the inputs would be used to drive the system to produce an optimal output across all the inputs, states, constraints (for example, budget), and other factors. The spectrum quantization engines are further described next starting with the MOO engine.
The MOO, also known as Pareto *efficient frontier*, is a nonlinear mathematical decision-making method of finding the “best fit” solution that simultaneously satisfies one or more *cost functions* or *objective functions* over a range of multiple, competing variables called *state* or *decision vectors* (Emmerich & Deutz, 2018). Cost functions are akin to goals or objectives to be achieved in a problem solution. The method involves iterating over the values and weights including constraints of each variable in relation to all other variables and corresponding objectives, converge to their minima, and satisfy the cost function(s). In effect, each variable “competes” with all other variables and the goal is to find a set of final values that do not maximize other variables to arrive at a solution that satisfies the cost function(s). According to Emmerich and Deutz (2018), a MOO problem can be mathematically formulated as

\[
\text{Min} \left[ f_1(x), f_2(x), \ldots, f_m(x) \right] \text{ such that } x \epsilon X \text{ and } f: X \to V^m, f(x) = [f_1(x), \ldots, f_m(x)]^T.
\]

In the above expression, \( x \) is the vector of design variables that are elements of set \( X \) or the feasible set of decision vectors, \( f_i(x) \) is the vector-valued cost function, \( V^m \) is the feasible set of vectorized solutions, the integer \( m \geq 2 \) refers to the number of competing objectives (greater than one), and \( T \) denotes the transpose of the vector-based set. In the context of developing a customized STEM program and an optimized curriculum, the values of \( x \) refer to the study variables and their assigned “values” that are fed into the STEM prism. The iterative MOO approach determines minima and maxima states of all variables within a given local set or over a global domain of feasible values. The implications on STEM program and curriculum development are profound in this case. The MOO decision-making can be used to compute optimal outputs for the inputs described above.
MOO has been used extensively in the fields of scientific research, digital communication, economics and financial forecasting, and supply-chain logistics where optimal decisions and tradeoffs must be made in view of multiple competing objectives. In most practical MOO problems, there can be more than three simultaneous cost objectives. An example of the application of MOO is a variation on the traveling salesperson problem which asks, “Given a list of homes in multiple cities and the distances between each pair of homes, what is the best way to visit each home using the shortest possible route in the shortest amount of time and return to the origin with the best sales outcome?” The multiple competing objectives are the shortest route, shortest time, best sales outcome, and the most successful home visits. The set of discrete and random variables are the number of homes, availability of customers, method of transportation, traffic conditions, and a multitude of other factors. The idea is to optimize the routing to reduce time and obtain the best sales outcome. One can see that probabilities and uncertainties arise in arriving at a practical solution in the presence of random variables.

The COOP engine, derived from marketing and business, is used to accelerate decisions by applying weights, priorities, and iterative adjudication to resolve competitive bottlenecks and ensure cooperation among competing decision vectors. The ROSE engine is used to apply constraints expressed as $g(x) \leq 0$ and to test outcomes based on relaxing or tightening the constraints. In effect, ROSE is a policy-based engine. When two or more factors are being decided on, the MOO engine, in conjunction with ROSE and COOP engines, has the computational horsepower to support iterative decisions on multiple state variables to produce optimal outcomes. Additionally, a priori and a posteriori conditions can be assigned to further optimize the iterative process to converge.
on acceptable solutions. The MOO is often used to handle sustainability problems; for example, to achieve and maintain the goals of high STEM engagement and persistence.

The approach would employ automated content analysis of the articulated thoughts of STEM learners and educators to craft purposeful, customized curricula and to fill learning gaps for enhanced engagement outcomes. The recommendations for state education and legislative bodies regarding STEM program reforms are presented in the next section.

Actions for state education legislative bodies – galvanizing efforts toward progressive STEM awareness and impacts on communities of interest. The study led to one main recommendation for the state education bodies that have charge over crafting and passing legislation in support of educational initiatives, programs, and reforms. An important leadership imperative emerges in passing STEM curriculum reforms that impact general education and higher learning institutions and instructional leaders. The international and statewide statistics on gaps in STEM proficiencies and on filling STEM occupations tell the whole story. The growing STEM gap compels state education and legislative leaders to consider revamping current STEM curricula and narrowing the gap. To that end, the findings of this study can be used to inform legislative reforms that would bring STEM pedagogy well into the 21st century. A four frames leadership model focused on leveraging the political frame would be advantageous to push for changes (Bolman & Deal, 2017).

The recommendation is to form a lobby group consisting of leaders from the higher education sector (presidents and provosts) along with leaders from secondary schools and districts (superintendents, assistant superintendents, principals, and vice
principals) who agree on the futility of high-stakes test standards and recognize that change is inevitable. The lobby group could include representatives from STEM industries. A legal spokesperson could be appointed to speak on behalf of the group on the STEM reform agenda. The lobby group would work with the state education board and department of education including state and federal politicians to bring to light the STEM gap issue and ways to overcome the gap through STEM program reforms.

The reforms would address ways of improving preservice teacher and counselor preparedness at institutions of higher education. The goal would be to raise awareness of progressive, in-service STEM pedagogical strategies and the need for informed counseling at the secondary school level. Furthermore, the reform agenda should include a plan to phase out or phase down high-stakes state testing and scripted programs, including the use of test scores as the key performance measure tied to teacher assessments, which is considered by many to be outdated and sets the academic system up for failure. The agenda would also identify ways to streamline the adoption of novel STEM practices and strategies for approving progressive STEM reforms. It would also address issues on the lack of informed school counseling on the realities of STEM fields and careers. Industry leadership perspectives and inputs would play favorably in this regard to highlight the needs and realities of workforce preparedness. The lobbying strategy should focus on community building, job growth, economic expansion, and the relevant social justice themes to justify the STEM reforms.

It is important to arm the state education and legislative leaders with the statistical facts and figures and new insights that will prompt a change in the future STEM pedagogic landscape. The implication here is to launch a tactical operation that will stir
dialogue, thought, and brainstorming along with developing cost-effective budgetary models to support initiatives. The state education and legislative leaders must be convinced by the data and must see a practical way forward with willing partners to implement changes. A progressive agenda is again viewed through the lenses of integrated, multidisciplinary, content-diverse, interactive, immersive, inquiry-based, and experiential learning that is non-siloed and non-classroom-confined, and that emphasizes real-life problem-solving—active, constructivist problem-based learning that taps into practical applications (Smith, Douglas, & Cox, 2009). The progressive curricula and programs must have traction, consistency, and reliability for long-lasting effect and be cost effective to implement on an annual basis.

Central to the argument in favor of progressive STEM reforms is the need to overcome a monolithic path to an uncertain success (trunk model) by employing an approach that offers flexibility, options, and a diversity of opportunities for a more deterministic and positive outcome (branch model). Recall that today’s STEM workforce depends on individuals with more diverse skill sets, agility, flexibility, and a capacity to focus their core skills and abilities, as necessary. Therefore, the imperative is to ensure that a more natural and conducive STEM “grooming” approach is established with enhanced engagement and persistence outcomes.

The STEAM translation pyramid and STEM prism of Figure 5.1 and Figure 5.2, respectively, are again proposed as methods of serving this agenda. Recall that the STEAM translation pyramid is derived from the LTM theory (Lesh & Doerr, 2003; Lesh & Harel, 2003). It provides a foundational framework for the STEM prism concept. Indeed, other programs and strategies could be considered such as brain learning or
others. The findings on brain-based learning theory, environments, and strategies can be used to optimally frame STEM curricula delivery given class environmental factors and goals and to accelerate the strategy for successful outcomes (DiTullio, 2018). Once again, the state education and legislative bureaucratic processes to enact such change are expected to be challenging.

Without significant reforms, the rate of teacher attrition will increase, and the students will be denied valuable academic and career opportunities. The change would affect learning environments, modalities, and policies and include a shift in teacher responsibilities along with a restatement of academic STEM goals. Ultimately, the inability to reform current processes would be a disservice to students and become a personal deterrent to STEM engagement. Adopting progressive reforms would achieve a better balance in STEM engagement in the near term and prepare the way for incremental improvements over time.

Recall, several of the educators in the focus groups stated that the school district and state education board expected them to devise plans for institutional cultural change using models by George Couros (“21st century innovation mindset”), Steven Covey, Carol Dweck (“growth mindset”), and others (Couros, 2011; Couros, 2015; Covey, 2006; Dweck, 2015; Dweck, 2016). Although the models were often used to define the requisite steps for affecting systemic change, they were not always systematically or consistently put into practice at the level of higher education. Therefore, the inability to put such models into practice or if their impact was local and sporadically felt, rather than widespread and consistently applied, contributed to the STEM gap. A call to action is
needed to implement, monitor, and refine a real, well-intended process for full impact and measure instead of a superficial plan that would barely *move the needle* on progress.

Eventually though, a tipping point is expected where reforms will be more readily adopted in the face of a continually eroding STEM workforce, in view of the international test scores and statistics on U.S. STEM proficiencies, and an outpacing in technical innovation by other nations. The solution to the problem is closely tied to reforming the high stakes testing model that currently exists, which requires the intercession of the state education and legislative leaders. The next section identifies several recommendations on future research based on the findings of the present study.

**Future research.** In the present study, no empirical research was uncovered that specifically examined the gaps that contribute to STEM disengagement between one’s senior year of high school and upon entering college or the workforce. The focus of the present study was to identify the factors that could “flip the switch” in one’s decision to pursue STEM or not upon high school graduation. The factors that were identified and explained in this study pertain to a specific research context—ESM High School. The present study opened the door to several follow-on areas of research. Four specific recommendations for future research are proposed.

The first recommendation is to examine the progress in implementing progressive STEM learning strategies and STEAM theoretic frameworks in elementary, middle, and high school settings. Whereas the present qualitative study focused on seniors in a suburban high school, the study should be extended; quantitative, mixed-method, longitudinal, and grounded theory studies would provide a granular understanding of the cumulative impact of such programs on student STEM engagement throughout their
formative years to uncover new gaps or further corroborate known ones. Future studies should consider research contexts and participants in a variety of academic settings including rural and urban inner-city school districts and during the first year of college/university to further broaden an understanding of the efficacy of progressive STEM learning models and associated gaps.

The second recommendation is to examine more closely the dynamics of small group learning on STEM engagement. Springer and Stanne (1999) showed that STEM learning outcomes increased in small group settings and supported the idea of implementing widespread small group learning in secondary and higher education institutions. Their findings were used to inform institutional policy and practice. However, the present study showed the opposite outcome. Although the present study was confined to a specific research context, examining the issue in other contexts or settings would enhance an understanding of group synergies on STEM learning and engagement capacities. Small group learning is worthy of further study amidst the ubiquity of digital remote learning tools and environments. Anecdotal evidence during the COVID-19 pandemic surfaced at the time of the present study that suggested technological and social distancing challenges as the downsides of digital remote/online learning from the students’, teachers’, and parents’ perspectives.

The findings of the present study bear a closer examination of the ways music can become part of the STEM learning experience. The present study found no strong, explicit link between music and STEM engagement despite the corroborative evidence in the literature to the contrary (Daugherty, 2013; DiTullio, 2018; Gordon et al., 2018; Hummell, 2014; Slater et al., 2017; Wu et al., 2015; Wynn & Harris, 2013). Therefore,
the third recommendation is to conduct a mixed-modes study using a music-based intervention to thoroughly study the impact on STEM learning and brain learning mechanisms that can affect STEM engagement.

Next, the domains of artificial intelligence (AI), machine learning (ML), deep learning, reinforcement learning, and neuromorphic computing attempt to adapt human learning models and event-driven decision-making algorithms to robotics devices. However, many challenges remain in entrusting full autonomy to machine-based and robotic devices. Humans must remain “in” or “on” the loop. Additional barriers exist in imparting “emotion” and creativity to robotics devices. Most of the game theory research to date has incompletely adapted the left-brain-logic modality to machines. Much research remains to determine how to impart the right-brain-creative modality to robotic devices although some gains have been made in this area of research. Nonetheless, the body of research to date has not thoroughly considered how to completely or successfully define autonomous systems that capture and mimic ways humans think and react using a STEM versus STEAM learning theoretic model.

At the commencement of the study, the knowledge gained from the brain learning studies in STEM pedagogy was thought to be able to inform scientists on new ways of imparting artificial intelligence algorithms in machine learning, neural networks, and robotic devices. The relevant findings on brain learning in the present study provide a foundation for the fourth recommendation. The recommendation is to use the results of the present study to inform the fields of AI and ML to advance the state of the art using the STEAM translation pyramid as a new, theoretic framework.
A basis for the fourth recommendation is found in the extensive body of literature that can inform the AI/ML fields of research from the perspective of neuroscience, cognitive science, and education including the advantages of combining disciplines for transdisciplinary and deep learning (DiTullio, 2018; Flogie & Aberšek, 2015; Henrkisen, DeSchryver, & Mishra, 2015; Neve, Hart, & Thomas, 1986; Tokuhama-Espinosa, 2011; Zadina, 2015). Caine and Caine (1994), Jensen (2008a), and Jensen (2008b) addressed brain-based interactive learning environments to promote individual creativity, conceptual understanding, and disciplinary connections in the presence of “threats” or stimuli that can affect attitudinal posture and decision-making capacity for active processing tasks. Hart (2002) likened the human brain to the digital computer in its ability to store programs and execute tasks amidst multiple environmental stimuli including threats. Neve (1985) described the importance of minimizing the threat to facilitate interactive communication, data sharing, and learning through real-life problem-solving engagements. AI/ML-based systems are designed to react to stimuli and perform decisions in real time and thus would benefit from the findings of the present study through follow-on research studies.

The STEAM translation theoretic model has implications on an evolving domain of AI/ML research coined by the researcher as Fine-Artificial-Intelligence, which infers the integration of fine arts aspects into logic-driven artificial intelligence expert systems. The DARPA MUSIC project recounts how music-theory-based algorithms were used to enable a jazz-playing robot to “jam” with human counterparts (Choi, 2015). It is envisioned that the STEAM theoretic framework can act as a catalyst for embedding and
linking left- and right-side neural algorithms to train AI/ML systems to enhance reasoning and understand causation across the science and art spectra.

The AI/ML approach is complemented by soft-skill-centric rule-based programs, integrative machine coding, neural networking architectures, reverse engineering methodologies, heuristic training protocols, and the application of moral and ethical constraints on machine processes (Anderson & Anderson, 2007; Bergstein, 2020; Besold & Uckelman, 2018; Bhattacharya, Yonggui, & Dongming, 2010; Bogosian, 2017; Brincker, 2016; De Loor, Manac'h, & Tisseau, 2009; D'Mello, Dieterle, & Duckworth, 2017; Downing, 2007; Edelman, 2016; Ginsburg & Budiardjo, 2019; Gürcan, 2014; Krüger, Kragic, Ude, & Geib, 2007; Piscopo & Birattari, 2008; Schultheis, 2007; Thórisson, 2007; Worgan & Damper, 2009). The relevant concepts and strategies have significant implications on advancing the broad field of artificial intelligence. A summary of the present study based on the analysis and results is provided next.

Conclusion

The qualitative case study examines a critical gap that exists in STEM engagement from the time of high school to when one enters college or the workforce. The gap is well documented in the literature. Gonzalez and Kuenzi (2012) reported declining trends in STEM persistence and increasing STEM pipeline leakage. A Pew Research Center report (2017) claimed that the US fell in the middle of the 2015 PISA test scores in science, math, and reading compared to all other countries around the world. The most recent Pew findings confirmed that the trend is far from improving. Lazio and Ford (2019) reported that the US currently has millions of STEM jobs that remain vacant.
Employers find it challenging to hire U.S. STEM graduate students with advanced masters and doctorate degrees and often have no choice but to hire foreign nationals to fill important STEM research positions. Simply stated, the STEM jobs are not being filled at a rate fast enough to match recruitment goals and that overcome losses due to attrition. The STEM labor supply is imbalanced in favor of the demand-side with a dearth on the supply-side. Clearly, the U.S. STEM pipeline is broken, and the problem continues to worsen. The implications of these basic findings on ESM High School in Central New York State are presented in the study.

High school is considered the “last stop” in grooming true and meaningful interest in STEM and in feeding the STEM workforce pipeline. The research particularly focuses on STEM engagement upon the time of high school graduation and reveals ways of closing the STEM gap following graduation. The research questions draw on the perspectives of STEM high school seniors and adult educators at ESM High School to determine the factors that stimulate STEM interest and that contribute to STEM disengagement upon graduation, consistent with the case study research methodology. The study explores the state of STEM pedagogy at ESM High School and to what extent progressive STEM learning programs and theoretic frameworks are implemented. The literature review delves thoroughly into the overarching factors that contribute to the STEM gap problem and identifies viable interventions that are contrasted with the data findings of the study.

The empirical studies address experimental interventions or institutional reforms designed to increase STEM engagement and reduce the gap. The research on the causes for the STEM gap over the past 10 years points to the growing importance of progressive
In nearly every case, the interventions fundamentally employ variants of integrated, multidisciplinary, and active learning protocols that address real-world problems instead of traditional, siloed STEM learning protocols using abstracted problem-solving contexts (Glancy & Moore, 2013). The study views the STEM gap problem through the lens of Lesh’s translation model (LTM) theory, a theoretical framework that exploits the power of integrated, multidisciplinary synergies and micro-agent interactions for STEM learning (Lesh & Harel, 2003). The LTM theory is used to explore and interpret the focus group data and to conceptualize interventions for increasing the students’ STEM affinity and level of engagement.

A new theoretic framework is derived based on the tenets of the LTM theory—called the STEAM translation pyramid. The new theoretic framework bridges the STEM disciplines to each other and to selected non-STEM (fine arts) subjects providing the basis for an effective, integrated, multidisciplinary intervention designed to revitalize STEM pedagogy and enhance long-term STEM engagement. The hope is that the secondary schools, with the support of the state and higher education institutions, will be proactive in adopting a framework for increasing meaningful STEM engagement and to continually feed the STEM pipeline to assure high persistence outcomes.

A qualitative case study methodology was used to answer the research questions. A total of six independent focus groups were conducted consisting of three student focus groups and three educator focus groups each with typically five to seven participants per group. The focus group questions were semi-structured to facilitate open dialogue and spur intragroup interaction. Gathering data based on educator and student perspectives was found to be invaluable in triangulating the results and sifting out emergent themes in
the study. However, the student perspectives were of main interest in the study. The data were analyzed individually by focus group, then synthesized across the educator focus groups independent of the student focus groups, and finally across all groups collectively to provide a final set of conclusions.

A gap was found in the literature regarding studies on STEM engagement, retention, and persistence involving STEM educators and high school seniors on the verge of graduation. The study was therefore aimed at this demographic to identify pedagogical or environmental factors that could cause students to abandon STEM pursuits upon graduation. Although the study and its results are unique to ESM High School and its Spartan Academy STEM Program, many of the findings highlight a broader gap issue leading to a set of recommendations. The focus group participants shared their understanding and experiences on STEM learning, the implementation of specific strategies and interventions, barriers to implementation, and any pitfalls in higher education STEM teacher and school counselor preparation training programs. In addition to the focus groups, field notes and audio/video recordings were used.

The study findings unveil a myriad of underlying factors contributing to the STEM gap. A subtle theme surfacing from the study is that a monolithic or one size fits all approach to STEM learning is a futile endeavor. Although the STEM pedagogical landscape has evolved in recent years, some study participants feel that more time is needed to measure the impacts of past changes. Overall, five factors emerge in the study as the main culprits contributing to the STEM gap. The factors are prioritized as follows:
1. The high stakes testing regime associated with the Common Core State Standards and the Common Core Assessments—the study deems this finding as the single most significant barrier to STEM engagement;

2. The barriers to rolling out a progressive STEM pedagogical model integrating non-STEM content to replace rigid, siloed STEM learning;

3. The lack of informed STEM college/career guidance by school counselors (an unanticipated finding);

4. Nonoptimal STEM marketing and conflicted messaging that attempts to appeal to those with low STEM affinity instead of engaging those who are already STEM-disposed; and

5. “Cultural” imbalances in expectations and responsibilities between secondary schools and higher education institutions on grooming master class STEM proficiencies.

Other factors include: a lack of awareness training on progressive STEM learning approaches, math phobia (where math provides a common, underlying framework that interconnects STEM and non-STEM subjects), over-propagandizing STEM, social justice fears of denying opportunities for underserved or disadvantaged groups, respecting one’s free choice in their decision to pursue a professional STEM degree versus a technical vocation/trade career path, and fostering an entrepreneurial mindset that shifts one’s thinking from a fear/flight mode to embracing risk. Additional unanticipated findings from the study are:

- No significant link was found between STEM engagement and music despite literature review findings to the contrary;
• Small group collaboratives did not lead to productive outcomes despite literature review findings to the contrary;
• Excessive use of technology can detract from meaningful STEM learning;
• Non-STEM (fine arts) interests can act as a catalyst for STEM attrition; and
• A perception emerged on the association between human STEAM learning and machine-based artificial intelligence (AI) learning.

The study findings further reveal that the high school educators are familiar with progressive STEM learning strategies but again, are limited to the extent that such strategies can be rolled out because of the constraints imposed by the Common Core State Standards. The educators are frustrated at the restrictions set by the state testing standards and suggest eliminating testing altogether because it sets up the academic system for failure and is largely to blame for the STEM gap. The students also find progressive STEM programs to be advantageous in ramping up their level of engagement. Indeed, STEAM pedagogy is a recurrent theme emerging from the study findings which integrates STEM and the arts. Unlike the educators, the students feel that progress is being made, but that more must be done to assure consistency and continuity in STEM pedagogical policies and practices for K-12 grades.

Overall, progressive STEM pedagogy is marginally integrated at best into the high school STEM curriculum and headway on this front remains slow. Another apparent gap exists—the lack of adopting progressive STEM strategies and interventions by state education bodies and the support of higher education institutions. Preservice teacher preparedness training in progressive STEM interventions at higher education institutions is at an insufficient level, and the state department of education is less then
proactive in supporting reforms to curb STEM attrition; yet the K-12 educators are expected to implement evidence-based strategies for reform with limited to no resources or outside support (Couros, 2011; Couros, 2015; Covey, 2006; Dweck, 2015; Dweck, 2016; Reid, 2012).

Although the strategies and models are often used to define the requisite steps for affecting systemic change, rarely are they systematically or consistently put into practice at the level of higher education. Therefore, the inability to put such models into practice or if their impact is local and sporadically felt, rather than widespread and consistently applied, widens the STEM gap. A call to action is needed to implement, monitor, and refine a sincere, well-intended process for full impact and measure instead of a superficial plan that barely moves the needle on progress. The high school STEM faculty unanimously agreed that progressive STEM learning strategies and interventions could be made readily actionable if not for the barriers due to the state testing standards. Several important implications arise because of the state standards.

The implications for departments of education at institutions of higher learning are to reevaluate and modify their existing preservice teacher awareness and preparedness programs to include new content that naturally aligns with STEM and can influence STEM pedagogical reforms toward increasing student engagement. Particularly, the teacher preparedness training needs to be recalibrated to familiarize preservice teachers with new information on progressive STEM learning strategies and teaching practices. Such training will aid in shoring up efforts on behalf of STEM recruitment, retention, and persistence. The preservice awareness training will better prepare in-service teachers in crafting lesson plans that can catalyze STEM engagement and aid in rolling out
professional development programs in progressive STEM pedagogy. The idea is to better prepare in-service teachers to push for curriculum reform and help roll out novel, progressive STEM programs that selectively tap into the fine arts and collapse the siloes.

Additional implications on departments of education at higher education institutions are to reevaluate existing preservice school counselor preparedness programs and incorporate revised college/career awareness content aimed at STEM field placements. The idea is to enable school counselors to regain their intended role as informed college and career guidance experts. Further, higher education executive leaders and administrators should assume a greater role and responsibility for raising the students’ STEM proficiencies to be commensurate with the college/university curriculum, rather than expect the high schools to consistently produce students having master class STEM proficiencies. A balancing of the responsibility in this way will remove the burden from the secondary school educators to assure master class graduates who may or may not fit the STEM mold. The colleges and universities should also work harder at dispelling notions or preconceptions of elitism to democratize STEM education in the spirit of promoting social justice.

The implications for secondary schools are to reevaluate extant curricular practices and policies based on the state Common Core testing standards and to identify and rank critical STEM pedagogical reforms. The school districts can use the STEAM translation pyramid to identify curricular realignments that match the needs and goals of a progressive STEM learning agenda. The districts should also sponsor professional development awareness training to guide in-service instructional teachers in structuring purposeful lesson plans and modules that fit progressive STEM learning goals. The
faculty should provide inputs to prioritize or revise parts of the STEM curriculum to include teaching modules that leverage proven STEM pedagogical best practices. Furthermore, the faculty should be required to translate the STEAM translation pyramid research into practice using the conceptual STEM prism, which exploits the power of artificial intelligence (AI) to craft an optimized STEM curriculum or lesson plans based on specific institutional needs, conditions, and learning goals. The approach would employ automated content analysis of the articulated thoughts of STEM educators and students to develop ways of crafting a purposeful curriculum and filling learning gaps to enhance engagement outcomes.

Another implication for school districts is to offer professional development training in effective strategies for marketing, advertising, and outreach. The faculty should provide inputs on developing marketing materials to maximize STEM outreach and positive outcomes for students with moderate-to-high STEM disposition. An additional implication is the need to create conducive environments that pave the way for the reforms to take root by examining how academic facilities and physical spaces can be optimally configured.

The implications for secondary school in-service counselors are that the school administrators must reexamine resident counseling programs and include revised college/career awareness content aimed at STEM field placements. The school administrators should be required to provide resident training to in-service counselors. The revised in-service counselor training curriculum would redefine the counselor’s role and raise awareness of the “life realities” of pursuing a STEM college or career path by
weighing salary and self-interests against external career factors that influence one’s
decisions to enter a STEM field.

Specifically, the framework for an amended counseling program should
emphasize informed guidance on STEM college/career pathways that exploits a *cultural
values* mindset encompassing professional degree and vocational/trade pursuits that
allows the freedom to choose. The revised counseling curriculum, responsibilities, and
duties would also encompass soft skills development to ensure that the in-service
counselors effectively convey primary academic and career guidance to students. The
school counselors should continue to advise on academic matters but be better trained in
prioritizing their duties amidst competing needs to not dilute career counseling capacity
and to provide reliable and dependable guidance on core and elective course options.
Counselors should be attuned to STEM affinity cues and be well informed on the STEM
demands of higher education and the workforce.

The study also has implications for state education executive leaders including
state and federal legislators who can embrace the research to help drive STEM
pedagogical reforms. Such reforms not only help improve STEM engagement outcomes
for students regardless of socioeconomic or sociocultural status; they also translate into
job growth and economic expansion. The research base can inform the development of
legislation in support of STEM reforms at all echelons to benefit such outcomes.

DiTullio (2018) appropriately stated,

> It is easy for leaders to get caught up in trends in education that come and go. It is
imperative that executive leaders are wary of these trends and find legitimate
research to support or rebuff the trends so that they can make informed decisions about how they are to committing resources. (p. 129)

The international and statewide statistics on gaps in STEM proficiencies and the growing number of unfilled STEM occupations tell the whole story. The growing STEM gap compels the state education and legislative leaders to revamp the current STEM curricula and find ways to narrow the gap. To that end, the findings of this study can be a catalyst for enacting legislative reforms that would bring STEM pedagogy well into the 21st century. Indeed, one of the first reforms to examine is associated with the application of the Common Core State Standards.

The reform agenda should include a plan to phase out or phase down high-stakes state testing and scripted programs, including the use of test scores as the key measure of achievement tied to teacher assessments, which is considered by many to be outdated and sets the academic system up for failure. The agenda would also identify ways to streamline the adoption of novel STEM practices and strategies for approving progressive STEM reforms. It would also address issues on the lack of informed school counseling regarding the realities of STEM fields and careers. Industry leadership perspectives and inputs would play favorably in this regard to highlight the needs and realities of workforce preparedness. The lobbying strategy should focus on community building, job growth, economic expansion, and the relevant social justice themes that are well served by judicious STEM reforms.

It is important to arm the state education and legislative leaders with the statistical data and fresh insights that will prompt a change in the future STEM pedagogic landscape. Again, the implication here is to launch a tactical agenda that will stir
dialogue, thought, and brainstorming along with developing cost-effective budgetary models to support initiatives. The state education and legislative leaders must be convinced by the data and must see a practical way forward with willing partners to implement change. A progressive agenda is again viewed through the lenses of integrated, multidisciplinary, content-diverse, interactive, immersive, inquiry-based, and experiential learning that is non-siloed and non-classroom-confined, and that emphasize real-life problem-solving—active, constructivist problem-based learning that taps into real-world applications (Smith, Douglas, & Cox, 2009). The progressive curricula and programs must have traction, consistency, and reliability for long-lasting effect and be cost effective to implement on an annual basis.

Central to the argument in favor of progressive STEM reforms is the need to overcome a monolithic path to an uncertain success (trunk model) by employing an approach that offers flexibility, options, a diversity of opportunities, and freedom of choice for a more deterministic and positive outcome (branch model). Recall that today’s STEM workforce depends on individuals with more diverse skill sets, agility, flexibility, and a capacity to focus their core skills and abilities, as necessary. Therefore, an added imperative is to ensure a natural and conducive STEM “grooming” approach with enhanced engagement and persistence outcomes. Nonetheless, the path forward is expected to be challenging due to the inherent state education and legislative bureaucracy that slows the pace of change.

The leadership imperative is for institutional, administrative, and instructional leaders at the state education, legislative, district, higher education, and secondary education levels to collectively address the STEM gap issue, prioritize a set of reforms,
and to do so expeditiously. The lack of timely policy reforms to restructure STEM education must be overcome before true change can take place and the benefits realized (Ernst et al., 2018; Kezar and Gehrke, 2017). For without significant STEM reforms, the rate of teacher attrition will rise, and the students will be denied valuable academic and career opportunities. The change affects learning environments, modalities, and policies and includes a shift in teacher responsibilities along with a restatement of academic STEM goals.

The inability to reform current processes is a disservice to students and becomes a personal deterrent to STEM engagement. Adopting progressive reforms achieves a better balance in STEM engagement in the near term and prepares the way for incremental improvements over time. An improved outcome is of benefit to the social justice goals of equity, equal opportunity for high-paying STEM jobs, social mobility, competitiveness in innovation, skills development, economic prosperity, and life enrichment for all citizens. These aspects are important to everyone, but especially precious to disadvantaged, underrepresented, and underserved social groups including women.

Regardless, the STEM gap continues to widen despite the limited, past reforms that have been put into practice. Perhaps more time is needed to judge whether past reforms will produce desirable outcomes. Unfortunately, the body of evidence thus far shows slow and sporadic progress on this front. The STEM gap will remain problematic until more aggressive interventions are put into practice. A tipping point is expected where reforms will be more readily adopted in the face of a continually eroding STEM workforce. Change will accelerate with the continual decline in the international test scores and statistics on U.S. STEM proficiencies coupled with an outpacing in technical
innovation by other nations. The solution is closely tied to reforming the high stakes testing model that currently exists, which requires the intercession of the state education and legislative leaders.

Finally, in addition to benefitting STEM engagement goals and in the spirit of scientific advancement, the knowledge gained from this study can be used in other ways. For instance, the STEAM translation pyramid theoretic framework and the conceptual STEM prism can be used to inform scientists on ways to advance artificial intelligence, machine learning, and robotics technologies and applications to create intelligent STEM pedagogical agents, tools, and digital aids. The framework can be used to align seemingly disparate fields to extend frames of thought, discourse, and research on the interconnectivity of the art and science domains and to infuse emotion, creativity, and the soft sciences into the rigorous logic and computational engines of machines. Marr (2017) quoted Alan Perlis, computer science pioneer as follows, “A year spent in artificial intelligence is enough to make one believe in God.” Ray (2018) stated, “The primary aim of quantum artificial intelligence is to improve human freedom, dignity, equality, security, and total well-being.” Finally, in the end as Jerome (2018) appropriately alluded, what is sought is the science of creativity.
References


Colegrove, T. (2017). Editorial board thoughts: arts into science, technology, engineering, and mathematics - STEAM, creative abrasion, and the opportunity in
libraries today. Information Technology & Libraries, 36(1), 4-10. doi: 10.6017/ital.v36i1.9733


Miller, M. (2015). *The Internet of things: How smart TVs, smart cars, smart homes, and smart cities are changing the world*. Indianapolis, IN: Que Publishing.


National Science Foundation. (1996). *Shaping the future: New expectations for undergraduate education in science, mathematics, engineering, and technology*. Washington, DC: Report by the Advisory Committee to the National Science Foundation Directorate for Education and Human Resources.


Straus, K. (2018). *These are the skills bosses say new college grads do not have.* Retrieved from https://www.forbes.com/sites/karstenstrauss/2016/05/17/these-are-the-skills-bosses-say-new-college-grads-do-not-have/#122c8b485491


Appendix A

Student Focus Group Interview Protocol

The focus group interview sessions for the students participating in the East Syracuse-Minoa (ESM) High School STEM program or in-school cocurricular activity involved a series of probing questions on STEM engagement that derived from and expanded on the fundamental research questions consistent with the case study research method. Table A1 shows the alignment between the dissertation research questions and the specific focus group interview questions that helped to answer the former. The interview questions listed in Table A1 were posed to whole, homogeneous groups consisting solely of high school seniors who had participated or were to participate in an in-school and/or cocurricular STEM-type program or activity at the time of the research.

Multiple (up to three) focus groups (each consisting of $N_{fg} = \text{five to 10}$ participants) were solicited in advance from the sample population ascertained prior to commencing the study. The participants agreed in advance to voluntarily participate in the focus group interviews. Each focus group session lasted approximately 75-minutes in duration. The following procedure was used to prepare for and conduct the focus group interview sessions and data collection steps:

a. Using a nonprobability purposive sampling method, arrangements were made in advance with student participants who responded positively to an open invitation to voluntarily participate in the focus group; this was done in coordination with the high school administrator or academic official.
b. All participants were advised prior to the start of the focus group session that the interview results will be kept confidential, will not be published or disseminated, and will be shared only with the research site upon request. Permissions were sought of each participant in advance to record the session.

c. Qualitative data collection was emphasized using a semi-structured interview style with open-ended questions.

d. Video and raw notes were recorded, and the detailed transcripts were subsequently generated.

e. The transcripts were iteratively coded and analyzed manually and with a Computer Assisted Qualitative Data Analysis Software (CAQDAS) tool using in vivo coding.

f. A series of opening, warm-up statements and questions were posed as follows:
   
i. Thank you for your willingness to participate in the study.
   
ii. How are you today?
   
iii. Are you aware that the session will be treated as confidential?
   
iv. Are you willing to openly share your experiences on the topic of interest?

   Next, a series of in-depth questions were posed. The questions were of a semi-structured and open-ended nature and were designed to probe the factors that contributed to or detracted from STEM engagement and persistence especially at the juncture between a STEM-oriented student’s high school graduation and his/her entry into college or the workforce. The comprehensive set of focus group interview questions is listed in Table A1. The interview questions were designed to answer the research questions applicable to the student participants. The interview questions were kept at a reasonable
level and posed in a conversational style to stay within the prescribed focus session
timeframe while attempting to optimize the opportunity for gathering meaningful data.

An iterative approach was used to analyze and color-code the data gathered from
each focus group session to identify the key themes, results, and findings (Saldana,
2015). The raw transcripts were annotated as necessary to elicit important themes and
trends in the recorded data. Additionally, for the interviewer, care was exercised to limit
follow-up inquiries to a single question (for example, “Do you understand the question?”
or “Is some clarification needed?”) and to thank the students at the conclusion of the
session for participating in the focus group. Additionally, arrangements with the focus
group participants were secured/confirmed in advance of conducting the interviews to
assure the availability of participants during the scheduled sessions.
### Alignment of Student Focus Group Interview Questions with Research Questions

<table>
<thead>
<tr>
<th>Research Questions</th>
<th>Focus Group Question(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>From the student’s perspective, how does participation in a STEM learning program stimulate or deter interest in pursuing a STEM major in college or as a career choice?</td>
<td>Why (or why not) are you STEM-inclined and how do you rate your STEM affinity (high/low)? How would you describe your current STEM experience and its influence on your choice of a college major and/or career? How could creative learning environments further stimulate an increase in STEM engagement? How or why could integrated STEM learning be beneficial? Do you believe that STEM and the fine arts (e.g., music) are interconnected or should the subjects be taught entirely in isolation? Explain. How might non-STEM subjects like music enhance STEM engagement/persistence? How do you learn (tactilely, visually) and why do certain learning methods work best for you?</td>
</tr>
<tr>
<td>From the standpoint of students, why might STEM persistence or sustained STEM interest upon/after high school graduation be on the decline?</td>
<td>Has your interest in STEM in high school decreased, leveled, or increased? How and why? Do STEM education gaps exist and how could it be delivered more effectively for lasting effect? How do you feel about mathematics or the study the math? Do you fear or embrace math? If fearful of math, how would you overcome it? How do you think females view STEM as a college major or career choice? How could we better engage women, disadvantaged, or underserved groups in STEM?</td>
</tr>
<tr>
<td>From the perspective of students, how can interest in pursuing a STEM major in college or a STEM career be increased?</td>
<td>Why would you consider pursuing either STEM or non-STEM as a career choice (salary, advancement, challenge, opportunity, other)? How could STEM help to address or solve social justice issues and which issues are of concern? Are there any other thoughts or ideas on STEM engagement strategies you would like to share?</td>
</tr>
</tbody>
</table>
Appendix B

Educator Focus Group Interview Protocol

The focus group interviews sessions for the STEM educators from East Syracuse-Minoa (ESM) High School or onsite cocurricular activity involved a series of probing questions on STEM learning and engagement that derived from and expanded on the fundamental research questions consistent with the case study research method. Table B1 shows the alignment between the dissertation research questions and the specific focus group interview questions that helped to answer the former.

The participants were solicited in advance from the sample population ascertained prior to commencing the study ($N_{Ei} \sim 10$). The participants agreed in advance to voluntarily participate in the individual interviews. Each focus group session lasted approximately 75-minutes in duration. The following procedure was used to prepare for and conduct the focus group sessions and data collection steps:

a. Using a nonprobability purposive sampling method, arrangements were made in advance with STEM educators who had responded positively to an invitation to voluntarily participate in the focus group sessions; this was done in coordination with the high school administrator or academic official, as needed.

b. All participants were advised prior to the start of the session that the focus group results will be kept confidential, will not be published or disseminated, and will be shared only with the research site upon request. Permissions were sought of each participant in advance of the session to record the focus group.
c. Qualitative data collection was emphasized using a semi-structured interview style with open-ended questions.

d. Video and raw notes were recorded, and the detailed transcripts were subsequently generated.

e. The transcripts were iteratively coded and analyzed manually and with a Computer Assisted Qualitative Data Analysis Software (CAQDAS) tool using in vivo coding.

f. A series of opening, warm-up statements and questions were posed as follows:

   i. Thank you for your willingness to participate in the study.

   ii. How are you today?

   iii. Are you aware that the session will be treated as confidential?

   iv. Are you willing to openly share your experiences on the topic of interest?

Next, a series of in-depth questions were posed. The questions were of a semi-structured and open-ended nature and were designed to probe the factors that contributed to or detracted from STEM engagement and persistence especially at the juncture between a STEM-oriented student’s high school graduation and his/her entry into college or the workforce. The comprehensive set of interview questions is listed in Table B1. The interview questions were designed to answer the relevant research questions applicable to STEM educators. The questions were kept at a reasonable level and using a conversational style to stay within the prescribed focus session timeframe while attempting to optimize the opportunity for gathering meaningful data and insights from the participants.
An iterative approach was used to analyze and color-code the data gathered from each focus group session to identify the key themes, results, and findings (Saldana, 2015). The raw transcripts were annotated as necessary to elicit important themes and trends in the recorded data. Additionally, for the interviewer, care was exercised to limit follow-up inquiries to a single question (for example, “Do you understand the question?” or “Is some clarification needed?”) and to thank the educators at the conclusion of the session for participating in the interview. Additionally, arrangements with the individual interview participants were secured/confirmed in advance of conducting the interviews to assure the availability of participants during the scheduled sessions.
Table B1

Alignment of STEM Educator Focus Group Interview Questions with Research Questions

<table>
<thead>
<tr>
<th>Research Questions</th>
<th>Focus Group Question(s)</th>
</tr>
</thead>
</table>
| From the perspective of the educator, how do current STEM programs contribute to or detract from STEM persistence after high school, during college, and as a career choice? | How do STEM programs differ today based on your own past experiences?  
How does today’s STEM curriculum/agenda affect engagement and persistence and do gaps exist?  
How could creative learning environments further stimulate an increase in STEM engagement?  
How or why could integrated STEM learning be beneficial?  
Do you believe that STEM and the fine arts (for example, music) are interconnected or should the subjects be taught entirely in isolation? Explain.  
How might non-STEM subjects like music enhance STEM engagement/persistence?  
How do students learn best (tactilely, visually, small group collaboration, other)? |
| From the standpoint of educators, why might STEM persistence or sustained STEM interest upon/after high school graduation be on the decline? | Has student interest in STEM in high school decreased, leveled, or increased? How and why?  
How could STEM learning be delivered in a more interesting or effective way for lasting effect?  
Do you find students fear mathematics? How would you help overcome the fear if it arises?  
How do you think females view STEM as a college major or career choice?  
How could we better engage women, disadvantaged, or underserved groups in STEM? |
| From the perspective of educators, how can interest in pursuing a STEM major in college or a STEM career be increased? | How do you view inside- vs. outside-class STEM learning?  
In your experience, is small group collaboration beneficial? How and why?  
How could STEM help to address or solve social justice issues and which issues are of concern?  
Are there any other thoughts or ideas on STEM engagement strategies you would like to share? |
Appendix C

Individual (One-on-One) Interview Protocol for Students Post Focus Group

A limited number of individual interviews were planned for selected students who actively participated in a STEM-type program or activity at East Syracuse-Minoa (ESM) High School. Any student participants who might have expressed strong or even wavering opinions during the focus group sessions, were considered for an invitation to participate in a one-on-one interview. The indicator or trigger for the selection and invitation process would be determined per independent, nonintrusive, or passive observations from the researcher’s perspective during the focus group stage.

The one-on-one interview session would involve a series of probing questions on STEM learning and engagement. The questions derived from and expanded on the fundamental research questions consistent with the case study research method in conjunction with the following categories of interest: (a) general (all-inclusive) STEM program efficacy, (b) integrated STEM efficacy, (c) integrated STEM plus music, and (d) synergies between mathematics and music. Table C1 shows the alignment between the dissertation research questions and the specific one-on-one interview questions that would help to answer the former.

Specific participants would be solicited depending on reactions observed during the prior focus group interview sessions ($N_{SI}$ ~five to 10). Participants would agree in advance to voluntarily participate in the individual interviews. Each interview was
expected to last up to 75-minutes in duration. The following procedure would be used to prepare for and conduct the interview sessions and data collection steps:

a. Consistent with a nonprobability purposive sampling method at the commencement of the study, invitations would be sent to selected students after the conduct of the student-based focus groups, to invite them to voluntarily participate in the individual interviews. Arrangements would then be made to conduct the interviews with students who would have responded positively to the invitation in coordination with the high school administrator or academic official.

b. All participants would be advised prior to the start of the session that the interview results will be kept confidential, will not be published or disseminated, and will be shared only with the interviewee upon request. Permissions would be sought of each participant in advance of the session to record the interview.

c. Qualitative data collection was emphasized using a semi-structured interview style with open-ended questions.

d. Video and raw notes would be recorded, and transcripts subsequently generated.

e. The transcripts would be iteratively coded and analyzed manually and with a Computer Assisted Qualitative Data Analysis Software (CAQDAS) tool using in vivo coding.

f. A series of opening, warm-up statements and questions would be posed as follows:

   i. Thank you for your willingness to participate in a follow-on interview.

   ii. How are you today?

   iii. Are you aware that the interview will be treated as confidential?
iv. Are you willing to openly share your experiences on some additional topic areas of interest relevant to the main study?

Next, a series of in-depth questions would be posed. The questions are of a semi-structured and open-ended nature and were designed to further probe into the additional factors that contributed to or detracted from STEM engagement and persistence especially at the juncture between a STEM-oriented student’s high school graduation and his/her entry into college or the workforce. The comprehensive set of interview questions is listed in Table C1. The interview questions were designed to answer the relevant dissertation research questions applicable to students 18 years or older actively participating in ESM High School’s STEM program or activity. The questions were kept at a reasonable level and in a conversational style to stay within the prescribed interview session timeframe while attempting to optimize the opportunity for gathering meaningful data and insights from each individual participant.

An iterative approach would be used to analyze and color-code the data gathered from each interview session to identify the key themes, results, and findings (Saldana, 2015). The raw transcripts would be annotated as necessary to elicit important themes and trends in the recorded data. Additionally, for the interviewer, care would be exercised to limit follow-up inquiries to a single question (for example, “Do you understand the question?” or “Is some clarification needed?”) and to thank the students at the conclusion of the session for participating in the interview. Additionally, arrangements with the individual interview participants would be secured/confirmed in advance of conducting the interviews to assure the availability of participants during the scheduled sessions.
Table C1

Alignment of Student Individual Interview Questions with Research Questions

<table>
<thead>
<tr>
<th>Research Questions</th>
<th>Interview Question(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>From the student’s perspective, how does participation in a STEM learning program</td>
<td>Have you previously been exposed to a STEM or a STEM plus Arts (STEAM) program in school</td>
</tr>
<tr>
<td>stimulate or deter interest in pursuing a STEM major in college or as a career</td>
<td>and/or outside of school? How effective was it?</td>
</tr>
<tr>
<td>choice?</td>
<td>How would you describe your experience with STEM before and after participating in</td>
</tr>
<tr>
<td></td>
<td>the current in-school STEM activity?</td>
</tr>
<tr>
<td></td>
<td>How would you make learning environments more creative to stimulate STEM engagement?</td>
</tr>
<tr>
<td></td>
<td>How would you describe interactive, immersive, integrated STEM learning and why</td>
</tr>
<tr>
<td></td>
<td>could it be an effective strategy for increasing STEM interest?</td>
</tr>
<tr>
<td></td>
<td>How might non-STEM subjects like music enhance STEM engagement/persistence?</td>
</tr>
<tr>
<td></td>
<td>Are there non-STEM subjects that interest you the most and why?</td>
</tr>
<tr>
<td>From the standpoint of students, why might STEM persistence or sustained STEM</td>
<td>How would you fix STEM gaps? Be specific.</td>
</tr>
<tr>
<td>interest upon/after high school graduation be on the decline?</td>
<td>Why would an understanding of the interconnections between STEM (mathematics) and</td>
</tr>
<tr>
<td></td>
<td>non-STEM subjects (music) increase your affinity for STEM? Do you see the</td>
</tr>
<tr>
<td></td>
<td>relationships?</td>
</tr>
<tr>
<td>From the perspective of students, how can interest in pursuing a STEM major in</td>
<td>How do you view inside- vs. outside-class STEM learning? Is access to industry</td>
</tr>
<tr>
<td>college or a STEM career be increased?</td>
<td>experts important?</td>
</tr>
<tr>
<td></td>
<td>In your experience, is small group collaboration beneficial? How and why?</td>
</tr>
<tr>
<td></td>
<td>Are there any other thoughts or ideas on STEM engagement strategies you would like</td>
</tr>
<tr>
<td></td>
<td>to share?</td>
</tr>
</tbody>
</table>

464
Appendix D

Letter of Introduction and Informed Consent Form to Research Study Participants

Study Title: A Case Study on the Efficacy of STEM Pedagogy in Central New York State: Examining STEM Engagement Gaps Affecting Outcomes for High School Seniors and Post-2007 Educational Leadership Interventions to Reinforce STEM Persistence with Implications of STEM Theoretic Frameworks on Artificial Intelligence / Machine Learning

Researchers: Andrew L. Drozd, Cohort 5 Doctoral Student Candidate, St. John Fisher College Doctorate in Executive Leadership (DEXL) Program

Before agreeing to participate in this research, I strongly encourage you to read the following explanation of this study. This statement describes the purpose and procedures of the study. Also described is your right to withdraw from the study at any time. This study has been approved by the Institutional Review Board (IRB) of St. John Fisher College of Rochester, NY

Explanation of Procedures

This study is designed to examine the ways in which STEM (Science, Technology, Engineering, and Mathematics) education/learning can be modified or improved to enhance long-term STEM engagement and persistence beyond high school. I am conducting this study to learn more about this question since it has not been studied much in the past. Participation in the study involves participation in focus groups that will ask you basic questions about yourselves and your specific experiences with STEM education/learning environments and activities, and a selected number of individual face-to-face interviews, which will last for approximately 90 minutes each. The focus group and one-on-one interviews will be conducted by the researcher heading up the study, audio- and video-recorded and later transcribed for the purpose of data analysis. I will interview you (students at least 18 years of age actively participating in an in-school STEM program or activity) within a focus group session and possibly in a one-on-one setting and separately conduct focus groups for STEM educators. The focus groups and interviews will be conducted in a classroom, counseling/interview room, or a TBD facility at ESM High School.

Risks and Discomforts

There are no risks or discomforts that are anticipated from your participation in the study. Potential risks or discomforts include possible emotional feelings or expressions of strong opinions when asked questions during the interview.
Benefits
The anticipated benefit of participation is the opportunity to discuss feelings, perceptions, and concerns related to the experience of STEM education/learning, and to contribute to understanding of decision-making on behalf of efforts to modify, change, or reform current STEM educational/learning practices to enhance long-term engagement and persistence in STEM beyond the high school experience.

Confidentiality
The information gathered during this study will remain confidential in secure premises during this project. Only the researchers will have access to the study data and information. There will not be any identifying names on the interview transcripts; they will be coded for anonymity and the key to the code will be kept locked away. Your names and any other identifying details will never be revealed in any publication of the results of this study. The audio/video recordings will be destroyed at the completion of the study. The results of the research will be published in the form of a doctoral dissertation or research paper and may be published in a professional journal or presented at professional meetings. It may also be published in book form. The knowledge obtained from this study will be of great value in guiding professionals to be more effective in conducting STEM education to maximize students’ long-term engagement and persistence in STEM learning during college and in professional career pursuits.

Withdrawal without Prejudice
Participation in this study is voluntary; refusal to participate will involve no penalty. You are free to withdraw consent and discontinue participation in this project at any time without prejudice or penalty. You are also free to refuse to answer any question I might ask you.

Further Questions and Follow-Up
You are welcome to ask the researcher any questions that occur to you during the focus group or individual interview. If you have further questions once the focus group or interview is completed, you are encouraged to contact the researcher using the contact information given below. If, as a result of participating in this study you feel the need for further, longer-term support, you are welcome to contact Dr. C. Michael Robinson at crobinson@sjfc.edu.

If you have other questions or concerns about the study please contact the chair of the IRB (Dr. Eileen Lynd-Balta) at St. John Fisher College of Rochester, NY at (585) 385-8000 or via e-mail at irb@sjfc.edu.

I, _______________________________________ (name; please print clearly), have read the above information. I freely agree to participate in this study. I understand that I am free to refuse to answer any question and to withdraw from the study at any time. I understand that my responses will be kept anonymous.

__________________________________________   _____________________
Participant Signature       Date
If:
(a) you would like a copy of your interview transcript once it is available
(b) you are interested in information about the study results as a whole, and/or
(c) if you would be willing to be contacted again in the future for a possible follow-up interview, please provide contact information below:

**Check those that apply:**

___ I would like a copy of my interview transcript
___ I would like information about the study results
___ I would be willing to be contacted in the future for a possible follow-up interview

Write your address clearly below. Please also provide an email address if you have one.

**Mailing address:**

**Email address:**

**Researcher contact information:** Andrew L. Drozd, P.O. Box 543, Rome, NY 13442-0543

Name(s) of researcher(s): Andrew L. Drozd

Faculty Supervisor: C. Michael Robinson, Ph.D. Phone for further information: (315) 498-7237

Purpose of study: The purpose of the research study is to fill the gap in our understanding of the factors that contribute to or detract from STEM engagement/persistence particularly during the transition period between 12th grade and upon entering college or the workforce.

Place of study: East Syracuse-Minoa High School Length of participation: 5/15-12/15 2019

Method(s) of data collection: Unobtrusive/passive (non-interference based) observations, supervised focus group interviews, supervised one-on-one interviews, researcher field notes, STEM program materials

Risks and benefits: The expected risks and benefits of participation in this study are explained below:

No risk; the study will be confined to participants 18+ years of age and will be benign aimed at gathering focus group and individual perspectives to identify factors contributing to or detracting from STEM program pedagogy, engagement, and persistence to develop effective STEM curricula in the future

Method for protecting confidentiality/privacy of subjects: Informed consent, privacy pledge, name anonymity, and confidentiality statements signed in advance of data collection including no dissemination of results including the statement as follows:
PLEASE INCLUDE: Your information may be shared with appropriate governmental authorities ONLY if you or someone else is in danger, or if we are required to do so by law.

Method for protecting confidentiality/privacy of data collected: Use of password-protected computer files/storage and purging of information after 5 years of study with proof of destruction - see addendum

Your rights: As a research participant, you have the right to:

1. Have the purpose of the study, and the expected risks and benefits fully explained to you before you choose to participate.
2. Withdraw from participation at any time without penalty.
3. Refuse to answer a particular question without penalty.
4. Be informed of the results of the study.

I have read the above, received a copy of this form, and I agree to participate in the above-named study.

Print name (Participant)    Signature    Date

Andrew L. Drozd
Print name (Investigator)    Signature    Date

If you have any further questions regarding this study, please contact the researcher(s) listed above. If you experience emotional or physical discomfort due to participation in this study, please contact your personal health care provider or an appropriate crisis service provider (*Provide the number of a local crisis service referral center here).

The Institutional Review Board of St. John Fisher College has reviewed this project. For any concerns regarding this study/or if you feel that your rights as a participant (or the rights of another participant) have been violated or caused you undue distress (physical or emotional distress), please contact Jill Rathbun by phone during normal business hours at (585) 385-8012 or irb@sjfc.edu. She will contact a supervisory IRB official to assist you.

If audio and/or video (digital) recordings of interviews are used, the following addendum will apply:

All digital audio recordings and transcriptions of interviews will be maintained using a private, locked, and password-protected file and password-protected computer stored securely in the private home of the principal researcher. Electronic files will include assigned identity codes and pseudonyms; they will not include actual names or any
information that could personally identify or connect participants to this study. Other materials, including notes or paper files related to data collection and analysis, will be stored securely in unmarked boxes, locked inside a cabinet in the private home of the principal researcher. Only the researcher will have access to electronic or paper records. The digitally recorded audio data will be kept by this researcher for a period of 5 years following publication of the dissertation. Signed informed consent documents will be kept for 5 years after publication. All paper records will be cross-cut shredded and professionally delivered for incineration. Electronic records will be cleared, purged, and destroyed from the hard drive and all devices such that restoring data is not possible.
Appendix F

Aggregated Findings Across All Student Focus Groups

The focus group questions (FQ#) together with the codes derived from the third cycle of analysis were used to generate the findings that answered the study’s research questions (RQ#). The aggregated findings across all the student focus groups were used to answer research questions RQ1, RQ3, and RQ4. The findings for the student focus groups are provided in Table F1 below. The aggregated findings described the themes that emerged, their meaning, and how the themes answered the research questions.

Table F1

**STEM Gap Analysis: Aggregated Findings Answering Research Questions (Students)**

<table>
<thead>
<tr>
<th>Research Question (RQ#)</th>
<th>Relevant Focus Group Questions (FQ#), A Priori Dimensions, and Study Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>RQ1: From the student’s perspective, how does participation in a STEM learning program stimulate or deter interest in pursuing a STEM major in college or as a career choice? Answered by FQ1 – FQ7.</td>
<td></td>
</tr>
<tr>
<td>FQ1. STEM affinity: Organizational willingness to build and nurture STEM capacity beyond normal limits based on strong STEM affinity was found to be a critical gap. STEM pedagogy must build on existing STEM affinity (students’ predispositions to STEM) and nurture that affinity in a non-disjointed, non-forceful way rather than blindly outreaching to recruit/convince non-STEM candidates. Appeal to students with at least moderately high affinity. Employ new or novel STEM pedagogy best practices.</td>
<td></td>
</tr>
<tr>
<td>FQ2. Current experience influencing persistence: Continuity coupled with student persistence and building on early exposure with diverse offerings that matched student interests were synergistically influential in STEM engagement. A more balanced “push” toward college/professional and vocational/trade career pathways was called out (dispelling the myth that STEM is strictly a college/professional-level pursuit). Positive teacher motivation and experiences along with nurturing learning environments and exposure to real-world team settings, internships, and tours of engineering/technology companies enhanced STEM engagement. Peer influence affected one’s decision to pursue a college/professional or a trade/vocational career pathway. ESM High School’s diverse STEM offerings, electives, and clubs and the opportunity to participate in nontraditional STEM classes sparked interest and growth opportunities.</td>
<td></td>
</tr>
</tbody>
</table>
FQ3. Creativity stimulating engagement: Creative processes and environments in STEM pedagogy were considered paramount. Creativity enabled future thinking and elicited enjoyment that enhanced the STEM experience. Creative processes exploited synergies across a diversity of subjects to inform college/career decisions. Novelty, fun, and personal gratification were emergent themes. Introducing creativity into STEM learning was a benefit for increased engagement. Other benefits and best practices: (a) the freedom to engage in out-of-the-box brainstorming and experimentation (creative problem solving), (b) exploiting STEM and non-STEM synergies for innovation and purposeful (humanitarian) applications, and (c) the sense of personal achievement in applying creative, customized solutions that address real-world needs.

FQ4. Integrated vs. siloed learning benefits: An agreement on the importance of integrating the STEM subjects over a siloed approach was unanimous. STEAM/STREAM was thought to make STEM learning less rigid and formulaic. The benefits of multidisciplinary, integrated, and practical STEM problem solving in a group setting were recommended. ESM High School was rated high for its efforts at integrating the STEM subjects including certain non-STEM subject matter, but efforts should be expanded. The success of an integrated program/curriculum was teacher dependent where some teachers were in a better position than others to effectively relate the different content or subject matter. The teachers who taught multiple (STEM) subjects had a greater capacity for appreciating the underlying connections. ESM High School’s support of integrated STEM learning opportunities kept the students engaged and helped in their college/career decisions.

FQ5. Non-STEM (fine arts) connections: STEM plus the fine arts or STEAM, was considered an enabler for STEM engagement/persistence. The rigid STEM-only education and workforce agenda was found to be outdated and potentially misleading. The natural relationships and connections between STEM and the fine arts facilitated the emergence of self-expression, creativity, and innovation; however, a best-case strategy for achieving a connective fabric was deemed challenging due to the state standards and an uncertain strategy. ESM High School was already on a successful path; however, its efforts to bridge disciplines and programs required further development. The inclusion of the fine arts into the STEM curriculum was deemed beneficial to STEM learning and engagement, but a certain degree of skepticism existed regarding an effective near-term strategy and the long-term implications.

FQ6. Music stimulating engagement/persistence: There was no clear or obvious “entry point” for music as a STEM engagement enabler and no apparent evidence to suggest any impact on STEM engagement. The findings were inconclusive. Stimulating STEM interest was dependent on one’s interest in the domain of music and how it could be an engagement device by exploring the combination of technology, math, software, and art. Music could help face the rigors of STEM providing an “offramp” to understand and appreciate the inherent scientific context and mathematical structure.

FQ7. Effective learning modalities: Visual and tactile learning were cited as the most effective modalities. Learning through auditory stimulation or contexts was considered less effective. Music and sound were found to not be significant contributors to or enablers of STEM engagement vis-a-vis small-group PBL protocols. There was no clear indication of music/sound as a STEM enabler.

RQ3: From the standpoint of students (and educators), why might STEM persistence or sustained STEM interest upon/after high school graduation be on the decline? Answered by FQ8 – FQ12.

FQ8. Sustaining interest: STEM interests increased, plateaued, and remained high owing to ESM’s programs that combined STEM and certain fine arts content when possible. Specific enablers included: STEM program diversity; positive educator leadership; motivational teaching styles; collaborative group settings allowing for independent/individual study; nurturing environments; integrated curriculum; exposure to practical problem solving and actual workplace settings; and family influences and peer encouragement. Learning to embrace challenges and overcome failure as part of the STEM character building process was another common theme as were instilling self-efficacy, self-realization, self-attitude,
Research Question (RQ#)

Relevant Focus Group Questions (FQ#), A Priori Dimensions, and Study Findings

self-confidence, and increased self-awareness. Remaining open to accepting career guidance while exercising choice in navigating the “unknown” helped build confidence (a potential gap was identified).

FQ9. Pedagogical gaps and remedies: Several gaps were identified. One was ESM High School’s marketing and advertising of its STEM offerings. A more robust outreach campaign was needed to raise awareness targeting students internally and outside industries and institutions. STEM offerings were often “buried” or hard to find in the school’s catalogues and brochures, thus lessening STEM’s visibility. The marketing and advertising campaign led to low signups, scheduling conflicts, and decisions to cancel or preempt certain STEM classes forcing students into less desirable options. The current marketing approach with its myriad choices of non-STEM offerings and conflicting schedules have “interrupted” the longitudinal continuity and flow of students’ STEM learning since middle school, believed to detract from sustainable STEM interest. Improved STEM program marketing, advertising, and outreach should be extended to younger students. Another gap area was the need for more practical, real-world projects and adapting a college-level mindset that emphasized applied learning. Also recommended was access to corporate facilities or natural laboratory settings to expand the students’ experiences.

FQ10. Math phobia: The study determined that ESM High School provided a positive environment for math learning, including ways to manage or overcome math phobias and build students’ confidence in applying math. Teachers actively intervened to help students overcome their fear of math. A rubric was proposed to help the students develop the critical thinking skills and apply logic steps to solve complex problems and overcome math anxieties. Practical, real-world problem sets were recommended to see the math connections more clearly across multidisciplinary subject domains and applications. Acquiring the knowledge and skills and building math confidence positively contributed to STEM engagement.

FQ11. Female STEM engagement/persistence: An estimated 20% gender disparity in favor of males existed in STEM classes at ESM High School at the time of the study. Societal “norms” and family upbringing were among the contributors lending to the stereotypical beliefs on the expected roles of males versus females. Although the situation has been slowly improving, a significant gender gap persists. Leadership, organizational, and policy changes were called on to eliminate a “one size fits all” STEM strategy. Some possible remedies were proposed as follows: exposing females at a young age to STEM content; marketing STEM offerings to females but empowering them to make their own choices; and supporting females’ decisions to split off into STEM and/or non-STEM classes and customize the program to appeal to their specific interests. Not forcing females to follow a STEM path if they were less inclined to do so or not at all was important. ESM High School had successfully created opportunities for students to split off into STEM or non-STEM classes and customized the classes and school experience to appeal to individual interests and professional career pursuits. Nonetheless, barriers to females in STEM continue to exist and has been difficult to change. Some exceptions were noted, namely in the STEM-related fields of medicine, healthcare, medical technology, biology, and other areas. Peer influence played a role in pipelining females toward STEM when they saw other females do the same, thus casting a “safety in numbers” net providing a “safe space” for females to participate in STEM.

FQ12. Disadvantaged/underserved STEM engagement: No clear, best strategy existed regarding outreach for disadvantaged and underserved group STEM engagement. It was uncertain whether ESM High School had made any extraordinary attempts at STEM outreach or had any success in engaging underserved or disadvantaged groups. A proposed approach to democratize STEM would offer a flexible and responsive plan that creates opportunities and matches specific interests/needs to support STEM career pursuits (analogous to a STEM college and career center specifically for the purpose of serving underserved and disadvantaged groups). Further, the plan should focus on career paths and strategies that are not purely driven by salary or economic incentives and that would dispel any notion of STEM as aspirational—or reserved for the elite; rather, it would stress self-efficacy, self-improvement, advancement, and contributing to social well-being. Also proposed was a STEM marketing and outreach program customized to be inclusive of disadvantaged and underserved groups and offering financial
Research Question (RQ#)

Relevant Focus Group Questions (FQ#), A Priori Dimensions, and Study Findings

assistance or other incentives. A recommended strategy to dispel gender, race, and socioeconomic stereotypes would be to focus on aspiration versus situation; that is, encouraging one to seize the opportunity and exploit one’s potential to make a positive difference rather than dwell on socioeconomic status or condition. Attempts to force the STEM agenda were considered ill-advised; it was deemed more effective to nurture STEM engagement especially at a young age but enable informed free choice. Based on ESM High School’s outreach aimed at females, efforts in support of underserved and disadvantaged groups appeared to be underway, although more work was necessary to realize positive outcomes.

RQ4: From the perspective of students (and educators), how can interest in pursuing a STEM major in college or a STEM career be increased? Answered by FQ13 – FQ15.

FQ13. STEM influencers vs. non-STEM careers: ESM High School staff provided leadership and guidance on navigating the vast array of STEM and non-STEM higher education and career opportunities, but room for improvement was cited. A significant and valuable finding was that career guidance was routinely delivered by teachers instead of school counselors, highlighting an important STEM gap later corroborated by the teachers. Other variables were found to collectively be more vital in STEM career decisions over salary and compensation and personal interests. The other variables included: aspirational; market demand or job availability; the amount of “investment” willing to be made; and a host of other tangible and intangible factors. Females were often compelled to take a stand on the growth of women entering the STEM fields and that there were no limits (breaking through the “glass ceiling”) in response to disparity issues. Career decisions should not be based solely on personal interests or desires but should balance multiple factors (job demand, advancement opportunities, salary, and so on).

FQ14. Social justice: Recurrent themes were gender parity, equity, equal opportunity for high-paying jobs, reward and fulfillment, financial security, and personal happiness. Other social justice considerations included technology’s role in society for improved quality of life; opportunities and incentives for underserved groups; philanthropy and humanitarian needs; contributions to job growth and societal financial healthy; and corporate or other organizational outreach that can lead to myriad opportunities. The ESM High School STEM experience helped to inform students’ opinions on the value of STEM education and engagement and on the underlying social justice issues and leadership strategies.

FQ15. STEM thought leadership: Identified was the need for expanded outreach and advertising of the STEM program to elementary and middle school grades. The outreach should include marketing, presentations, and visits to describe traditional STEM/STEAM and specialized programs. Students should actively promote the STEM program by talking about their experiences and knowledge gained, friendships formed, and the many fun group activities and learning opportunities. Local technology companies should step up active outreach and engagement to offer internships, engineering scholarships, and financial aid/incentives for disadvantaged or underserved STEM-oriented students. Assuring the continuity in teacher/counselor/mentor support systems stood out as a major gap concern in the strategy to ensure informed guidance. High-level strategies were discussed for boosting the US’ ranking as a global STEM leader starting at a local or grassroots level. Counterpoints on U.S. STEM leadership raised concerns that were deemed counterproductive to the goals of the study. A comprehensive set of additional recommendations and best practices were proposed. ESM High School leadership, administration, and STEM teachers were generally aware of the need to make certain improvements or adjustments in current policies, procedures, and best practices that would help improve STEM engagement upon graduation.
Appendix G

Aggregated Findings Across All Educator Focus Groups

The focus group questions (FQ#) together with the codes derived from the third cycle of analysis were used to generate the findings that answered the research questions (RQ#). The aggregated findings across all the educator focus groups were used to answer research questions RQ2, RQ3, and RQ4. The findings for the educator focus groups as provided in Table G1 below. The aggregated findings described the themes that emerged, their meaning, and how the themes answered the research questions.

Table G1

STEM Gap Analysis: Aggregated Findings Answering Research Questions (Educators)

<table>
<thead>
<tr>
<th>Research Question (RQ#)</th>
<th>Relevant Focus Group Questions (FQ#), A Priori Dimensions, and Study Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>RQ2: From the perspective of the educator, how do current STEM programs contribute to or detract from STEM persistence after high school, during college, and as a career choice? Answered by FQ1 – FQ7.</td>
<td>FQ1. Past/Current STEM Pedagogy Experience: STEM programs have evolved at a relatively slow pace over the last 10 years. Present ESM High School STEM programs are considered more “liberal” but continue to embody a legacy of siloed learning burdened by state education constraints. The school has established itself apart from other CNY schools by having the core of a unique, progressive STEM program that integrates art electives on a case-by-case basis. The program seeks cross-disciplinary connections, engenders critical thinking, promotes problem-solving within real-world contexts, and supports career and technical education classes that has become a model for other CNY schools. STEM educators proactively seek ways to synergize aspects of STEM with other subjects. Some success has been achieved at incorporating science and technology in certain non-STEM classes but integrating math has been more difficult. The school continues to use PBL protocols and is pivoting towards a STEAM fabric via an integrative, multidisciplinary pedagogical approach. PBL protocols help students acquire the necessary soft skills and integrate them in STEM learning environments and activities. Current strategies to infuse the arts and humanities into STEM have been marginally successful and remain challenging. The school has taken steps to fill the STEM gap by eliminating a “one size fits all” (monolithic) approach. Ongoing challenges contributing to the STEM gap: (a) an inflexible and bureaucratic state education system that levies standards creating inertia to curricular change, (b) a lack of school career counseling that has fallen on the shoulders of the educators, (c) subject-class territorialism coupled with a fear of change, (d) limits on teachers’ time, staffing, and other school resources to more</td>
</tr>
</tbody>
</table>
Research Question (RQ#)

Relevant Focus Group Questions (FQ#), A Priori Dimensions, and Study Findings

fully exploit multidisciplinary synergies, (e) forcing students to choose from a myriad of electives that confuses and overwhelms them due to nonoptimal marketing and schedule conflicts, and (f) the notion of STEM as exclusive of technical vocation/trade fields. The gap is widened by a tension that exists in enabling a student’s free and fair informed choice regarding a college/professional vs. vocation/trade career path based on their individual interests using a cultural values model. Additionally, all access to too much technology at virtually anytime and anywhere is not always a benefit. Some current best practices: (a) the educators do not force or over-propagandize the STEM agenda in a way that could disengage interest, but instead attempt to raise awareness of the possibilities, empower independent choice, and encourage students to adopt an entrepreneurial risk mindset; (b) successfully connecting the STEM programs with industry and the business workplace; (c) dispelling the notion of STEM as elitist; (d) downplaying the stereotype myths about the rigors and demands of STEM fields compared to non-STEM fields in filling the gap; and (e) recalibrating the notion of STEM to be inclusive of technical vocation/trade jobs. Some areas of improvement: (a) adapting to meet the needs of each class of students going through the program, provide sound career guidance, enable informed career decisions, and encourage individual passions; (b) increase the number of internships, corporate scholarships, and college credits to resonant with STEM students’ fields of interest; and (c) improve the structuring, marketing, and implementation of a STEAM curriculum, which presently is loosely federated at best, to guide the students on a path towards their higher education and career interests. Cross-disciplinary coordination and support have been called for that bridges seemingly disparate domains as a way of expanding frames of thought and creating new opportunities to fill the gap.

FQ2. Present STEM Pedagogical Gaps: Underscored is the importance of a progressive STEM learning approach that exploits multidisciplinary synergies and practical contexts. The ESM High School STEM curriculum is encumbered by state education standards that contribute to the STEM gap. ESM High School has put into practice certain measures to roll out an integrated, interactive, multidisciplinary STEAM learning via PBL and complementary approaches. The gap relates to the teachers’ degree of latitude to implement new, novel strategies. The gaps are: (a) difficulty in breaking down legacy, siloed learning structures constrained by NYSED testing regulations and institutional frameworks driven to meet accountability and regional assessment standards; (b) institutional inertia coupled with staff logistical and time constraints that limit implementing multidisciplinary, application-based curricular models meant to assure continuity in experience from high school to post-graduation; (c) non-optimal communications and marketing of STEM offerings coupled with a wide array of options that confuse and overwhelm students; (d) disenfranchising those interested in STEM vocational trades from mainstream STEM opportunities; (e) school counselor unpreparedness in providing informed guidance regarding college, professional, and vocational/trade STEM career path options or opportunities; (f) the lack of support for students in confronting real-world challenges, making informed decisions, and culturing them to embrace and recover from failure; (g) challenges in inspiring a culture of curiosity and the practice of inquiry in accordance with NYSED’s Next Generation Science Standards (NGSS)—teaching students to ask the right questions and adopting a risk and reward mindset; and (h) managing the distractions of technology that can reduce attention span. A set of recommendations was offered to fill the gaps aimed at STEM students with high STEM affinity and those academically borderline in STEM: (a) exposure to real-world problem-solving opportunities inside and outside the classroom; (b) enable informed choice; (c) show students their capacity for change; (d) cultivate an institutional growth mindset via entrepreneurial principles; (e) mutual trust building; (f) assess lesson effectiveness; (g) provide a nurturing support environment; (h) show meaningful multidisciplinary connections; (i) replace standards competency based pedagogy with application- and outcome-based models; (j) ensure continuity in learning and understanding multidisciplinary synergies (thematic threading), set realistic goals, encourage experimentation, and power through failure to prevent disengagement; (k) inform high school counselors of the importance of inclusivity and fairness in promoting both college and vocational trade STEM opportunities by weighing cultural values; (l) crystallize the messaging and marketing/advertising strategies to raise students’ awareness and lower confusion or anxiety; (m) active student outreach;
(n) inform parents and families of STEM options for 2- or 4-year colleges, vocational trades, scholarships, internships, job market and timelines, and associated risks/benefits (ESM High School has demonstrated successes on this outreach front); (o) recruit industry experts to provide practical STEM education and training experience; (p) foster an integrated product team mentality early on for team building; and (q) show the interdisciplinary nature across subjects using concrete examples or practical problem sets, including the integration of English, arts, and the humanities into STEM for soft skills, combined with a content driving curiosity pedagogical approach.

FQ3. Creative Learning Environments: Creativity, often associated with non-STEM or arts and humanities subjects, is paramount to an effective and impactful STEM curriculum because it sparks innovation and leads to knowledge discovery. From the teachers’ perspective, the ESM High School students demonstrated a capacity to embrace non-STEM subject matter in STEM class projects. However, music as an art form was not explicitly identified as part of the creative tool set for any aspect of STEM learning or engagement. The ESM High School teachers have some latitude in introducing creative ways of teaching STEM subjects within reasonable and practical limits via PBL and hands-on activities. On the other hand, the school must exercise care in rolling out programs that could be deemed too risky or out of scope to avoid potentially jeopardizing STEM education grant funding.

FQ4. Integrated vs. Siloed Learning Benefits: An inconsistency in the way the NYSED standards are applied has created a discontinuity in the STEM program across the grades. Implementing change at the high school level has been challenging, slow to unfold, and somewhat limited in scope and impact. The overarching state education bureaucracy was deemed to be largely at fault. The system by default had fostered a siloed STEM learning mindset yet points to the need for a progressive curriculum and creative lesson planning. The dichotomous messaging and policies have led to STEM programs that were implemented nonuniformly or disjointly. The dichotomy forces high school STEM teachers to approach change in a cautionary way to preclude risks, although they have experimented with ways to cross-fertilize knowledge across different domains for the benefit of their students. The ESM teachers are making a gradual shift to a more integrated curriculum at least 1 day a week by having the math, science, and English teachers together in the classroom, although incorporating the math was problematic. Additionally, larger group sizes are preferred over smaller groups. Larger groups facilitate expanded conversation, brainstorming, teamwork and interactive collaboration, multifaceted problem-solving and shared (authentic) learning, productive behavior and engagement, and the refinement of skill sets. The small groups tended to be more limited along the above dimensions and virtually absent altogether in siloed settings. The ESM teachers explored the formation of multidisciplinary teams to synergize non-STEM subjects like English to improve science communications skills. Again, the constraints on the curriculum force teachers to focus on meeting the state education standards regarding testing, test scores, and teacher assessments, instead of pursuing novel STEM programs. An anticipated future shift will be towards applying literacy and critical thinking-based methods for STEM. A further shift would be to eliminate regional testing altogether. Teachers will need to acquire new skills and be well versed in multiple subjects; alternatively, specialists and outside experts can be recruited to help shape the new STEM pedagogical landscape. A “common planning” tool was envisioned to preclude interdepartmental “disjointedness” on behalf of meeting STEM goals. Marketing, public relations, and messaging are also key factors in any successful STEM program rollout. Success on these fronts is predicated on informed school counselors who can share the STEM vision and articulate the possibilities, options, and opportunities to students and their parents or mentors to secure STEM engagement. However, several of the ideas above had been considered in the past but not adopted. A complementary engagement strategy is to exploit self-motivational theories to stimulate one’s creative potential.

FQ5. Non-STEM (Fine Arts) Connections: Infusing selected aspects of the fine arts into STEM has been more of the exception rather than the rule and done on an experimental basis. Although a strong argument exists for incorporating the fine arts like music into STEM, it would only make sense if there was a specific reason or purpose to do so; otherwise, an artificial intersection of the two domains for the
purpose of promoting a STEAM agenda could “dilute” STEM’s impact. Several key findings emerged (majority in favor of 2-4): (a) avoid forcing the fine arts like music into STEM unless a reason exists, (b) acknowledge the state education standards and teacher time constraints as barriers that could limit experimentation and delay curriculum reform, (c) unconditionally change the STEM curriculum to integrate the fine arts, (d) exploit the belief that those who are music oriented are also math/science oriented, and (d) use music “immersion” as a tool to stimulate creativity in STEM learning and heighten the effectiveness of STEM multimedia content delivery. Highlighted is the importance of applying novel methods, like music-based interventions, to stimulate creative independent/team learning and critical thinking as part of a progressive STEM curriculum. Also, mathematics and music are thought to be strongly interconnected and the positive influences on left/right brain development, learning capacity through association, and creativity. Other fine arts like theatre, role playing, and improvisation are also effective tools for science communications, embracing multiple perspectives and comprehending diverse frames of thought, self-expression, and confidence-building. A positive view of music is that it acts as a gateway to other fine arts and humanities that intersect well with STEM to provide for new and rich contexts. Gaps arise in introducing the fine arts into STEM because of the state education standards. Many educators are disappointed in the lag and lack of progressive planning on this front. Many teachers believe that the longer it takes to expand STEM programs in this way, the more the students are shortchanged, and the greater will be the STEM attrition rate.

FQ6. Music Stimulating Engagement/Persistence: The true value of adding non-STEM subjects like music to enhance STEM engagement and persistence is unclear. There is little doubt that music can benefit STEM learning and engagement in some way by understanding the connections across the disciplinary domains. However, experts are concerned that STEM has been ill-defined in the absence of cross-disciplinary associations and call into question the effectiveness of today’s outreach tactics on long-term engagement. At the heart of the concern is enabling students to make their own academic and professional career choices while building on their interests. Related concerns are: making effective connections between math and music; the “reverse” effect of STEM exposure engaging interest in non-STEM careers; external factors influencing decisions (risk vs. reward, expectations and demands, stress or anxiety, and negative outcomes) especially in the case of students with low STEM affinity who are pipelined into STEM fields; uncertainty regarding personal interests versus career trajectory in view of professional versus trade/vocational STEM career pathways; and past ill-conceived strategies that have led to disengagement. STEAM provides a platform for envisioning the interplay of the musical notes, time signatures, and rhythmic patterns rooted in mathematics and science and that are resonant with the creative process. The STEM outward messaging has been confusing and conflicted, and the goals of recruitment are lacking vis-a-vis workforce preparedness. Schools and industries are “hyping” STEM sending a message that STEM is the only path worth taking and focusing more on a collage path vs. a vocations/trades path. Education experts point to a multiprong strategy for increasing STEM engagement fundamentally building on the premise of cultivating STEM affinity and implementing a forward-thinking STEM pedagogical model. The strategy respect students’ rights to choose in accordance with their personal interests and beliefs rather than having STEM foisted on them at the exclusion of all else. Further, teachers and counselors should deliver informed guidance to students and not discourage their dreams or tell them what they should or should not do as a career choice. Indeed, the message that the STEM community has sent in the past is overpowering and widens the STEM gap. The high school generally tends to emphasize STEM college paths over trade/vocational opportunities. Furthermore, although support exists for cross-disciplinary curricula that integrates STEM and certain non-STEM subjects like music as electives, it is only possible on a restricted basis due to the limitations of the state education standards, academic resources, and available personal time.

FQ7. Effective Learning Modalities: The learning modality of choice is student dependent with no single, preferred technique thought to always work best for everyone in every given situation. From the standpoint of individual learning, the top three modalities identified, in order of priority, were visual,
Research Question (RQ#)

Relevant Focus Group Questions (FQ#), A Priori Dimensions, and Study Findings
tactile, and experiential. Multimedia content delivery is most impactful to STEM learning and engagement, meaning a combination of visual, tactile (hands-on), auditory, and experiential learning that exposes students to real-world problem-solving sets. Practical, hands-on experience is a modality that is effective in surfacing a student’s abilities and reinforcing positive outcomes. Kinesiology learning was also identified as a potential modality. On the other hand, auditory learning, including the use of music or sound as a tool for increasing STEM learning capacity, was not identified as a priority learning modality; although, naturally developing good listening and verbal communication skills amidst lectures or discussions was important. Additionally, the conduciveness of the pedagogical environment to STEM learning is another important modality that also taps into group/team collaboration and group size dynamics. Team/group collaborations were overall considered unfeasible, awkward, and not able to produce the desired outcomes. Small groups were especially problematic and produced less-desirable outcomes than did larger groups citing soft skills gaps, particularly interpersonal communications skills, exacerbated by an overuse of social media platforms as a key contributor. Although that could change if strong, independent thinkers are in the group coupled with more hands-on opportunities. A progressive strategy to augment current learning modalities was proposed that progressively builds a teamwork mindset and that underscores the importance of developing effective soft skills. The strategy, as a type of modality, starts with independent reflection followed by a group session. Next, a lack of clear communications, counseling, and coordination at strategic points in a student’s career exists and can contribute to disengagement. The teachers and counselors are recommended to develop effective soft skills as a component of the STEM pedagogical strategy (again, a type of modality related to communications) to provide sound academic and career guidance to students. A critical need exists for teachers to acquire the necessary soft skills to help adjudicate curricular needs to meet the state standards versus what is in the students’ best interests. The underlying problem, however, is whether teachers should be responsible for assured students’ STEM proficiencies in high school to the point of producing “master class” scholars, or if it should be more about information sharing and providing guidance for them to achieve to the best of their ability. A combination of the ongoing pressures of state testing, using test scores as the key performance measure, teacher assessments, a lack of endorsement of current practices towards change, and a resistance to reforms creates stresses for students and teachers alike. Constantly coping with the stresses can lead to burnout, apathy, disengagement, shutting down, or retreat. Without significant reforms, the rate of teacher attrition will increase, and the students will lose out on valuable academic and career opportunities. Ultimately, the inability to reform current processes would be a disservice to students and become a personal deterrent to STEM engagement. A suggested approach to alleviate the problem is to change the scholastic grading system by eliminating state testing, which is considered outdated and sets the academic system up for failure. A recommended paradigm shift is to avoid over-dwelling on rigor in high school to meet the testing standards and place scholastic master class achievements on the shoulders of colleges, while delivering reliable college preparation content in high school. Adopting progressive reforms would achieve a better balance in STEM engagement in the near term and prepare the way for incremental improvements over time. Recommendations were offered to further extend the concept of STEM learning environments as a modality such as guiding students in building an academic and experiential portfolio highlighting real-world and hands-on project experience, practical training credentials and certifications, and college preparation courses taken without emphasizing state test scores. Some challenges exist in teaching classes of students across a spectrum of learning-disabled, behavioral, emotional, and other categories.

RQ3: From the standpoint of (students and) educators, why might STEM persistence or sustained STEM interest upon/after high school graduation be on the decline? Answered by FQ8 – FQ12.

FQ8. STEM Sustainability & Persistence: STEM interest has plateaued, and no surge was seen or anticipated in either direction in the near term. STEM affinity has a greater chance of transferring and persisting at least up to the time of high school graduation if students are “captured” at a young age to participate in STEM programs—pointing to a gap or an inconsistency in the way STEM pedagogy had
been implemented before and during high school. A paradigm shift in STEM education is called for, noting past attempts to redirect non-STEM students towards STEM only for them to become victims of STEM attrition over time. Part of the problem traces back to the disconnection between STEM and the humanities. The STEAM curriculum in high school remains very experimental and nonoptimal at best. Teachers should continuously nurture opportunities, build skills and confidence, instill a sense of empowerment and pride through accomplishment, and create pathways that move the students in a direction toward STEM interest and career success. However, an over-paced series of program trials results in “STEM information overload and is a detriment to STEM engagement.” The “disjointedness” of programs over time is leading to a confusing and bloated STEM education landscape, loss of focus, unachieved goals, and eventual teacher burnout and student disengagement all contributing to the STEM gap. The teachers are unable to effectively make interdisciplinary connections because of state curricular constraints and are losing touch with teaching the lesson fundamentals. Students become disillusioned with what they perceive to be a non-impactful program and with little choice but to drop out. The potential outcomes of not consistently delivering a stable, focused STEM program with a flexible set of options or electives and not enabling students a choice, are complacency and apathy. Students will retreat and fall into the trap of focusing on self-interests or pursuits they feel are beneficial to them without considering the larger picture. The students who disengage from STEM may convince themselves that overachieving for college is unnecessary. They will be less incentivized to hone their skills and be content just achieving a passing GPA. Another contributor to the STEM gap centers on the “no child left behind” theme where students are taught to “trust the process” and caught in the trap of doing what they have been told, “regurgitating” the curriculum, being ultra-cautious so as not to experiment and take risks and adhere to a culture of achievement defined by the state education standards built on a Regents testing/grading system. A progressive STEM learning model is unlikely to unfold in view of today’s constrained educational curriculum. Other contributors include family influences that drive the students to get good grades at any cost to qualify for college scholarships and reduce financial burdens; high school STEM graduates who met the minimum state standards and are “unprepared” for the rigors of the college STEM experience which could shock them into switching to a non-STEM major or dropping out altogether; and a higher benefit-to-risk ratio that a non-STEM major might offer in terms of a competitive salary and benefits, reduced commitment and scholastic intensity, and less stress. The source of the gap traces back to a bloated testing culture driven by state education standards coupled with school counselors who are uninformed or unprepared to offer effective guidance about the realities of the situation. Next, the federal government has “hyped” STEM to the point of creating a sense of urgency; however, the message lacks substance by not defining what STEM education truly means and how to develop and implement STEM programs for high impact. The messaging is vague and open to interpretation, leading to a wide array of programs that on one hand, can be beneficial in terms of diversity, but on the other hand, confusing and inconsistent with varied expected outcomes. The problem is also one of where or what to invest in. Whereas many good ideas have been conceived that have yet to be adopted for “mainstream” implementation, it is important to pick the right programs with a high return on investment and allow time for the gap to close. Finally, STEM marketing strategies and inward messaging fosters misconceptions that set STEM students up for failure as they enter college. High school students are a vulnerable group—they may be unsure of their college/career path and may have been encouraged or perhaps pressured to pursue STEM, and where non-STEM pursuits are frowned upon. Deciding to pursue a STEM path yet barraged by such messages as “STEM is hard” or “grades are key,” leads to a defeatist outcome. The conflicted messaging and resultant misconceptions about STEM as reserved for the elite, or that some majors were harder than others, may explain the “flip of the switch” culminating in STEM disengagement between high school graduation and the first year of college. STEM should not be advertised as something that only those with the “right credentials” should aspire to. STEM is simply not suited for everyone. Youth should be exposed to STEM but not be pressured into it, and students should be enabled to make their own choices. The viewpoint is thought to help make the difference in achieving true and persistent STEM engagement.
FQ9. Interventions/Remedies: ESM High School teachers and school counselors must be able to dispense authentic, informed guidance to students about STEM opportunities to the extent possible and enable them to autonomously make choices tempered by expert guidance. Teachers are trying to make interdisciplinary connections and “stretch” the curriculum when time and opportunity permit. Thematic framing is used to address a problem by having the students develop a multiprong strategy with a diversity of perspectives and go beyond just a scientific thought frame. Via the thematic approach, topics in science coupled with nonfiction English Language Arts (ELA) are used in situ to engage the students and facilitate open, diverse conversations on relevant interdisciplinary topics. Initiatives to actively pair subjects and show connections is a work in progress because of the need to resolve lesson block schedule conflicts among the teachers. Seeking ways for teachers from different disciplines to work together remains a common goal. More work is needed to implement effective approaches that include introducing as many practical, hands-on activities as possible and not creating “artificial” or forced connections that do not naturally fit together. The educators want to teach free from the burdens of the standardized test criteria. Standardized testing is deemed a barrier to true education. The overemphasis on test scores as a key performance measure is “superficial” to real or deep learning, is not an accurate reflection of success, and is meaningless or counterproductive to the goals of learning. Being consumed by the fear of passing the tests is not only psychologically stressful and unhealthy for students but could negatively impact their decision to pursue a STEM field in college. STEM curriculum change cannot be on the teachers’ shoulders alone; it also involves the cooperation of the district and state education agencies. Concern exists over the need to take more aggressive steps at implementing changes to a rigid system by the school district and state education leaders to prevent STEM erosion. ESM High School advertises its interdisciplinary STEAM program but realistically, it is limited and sporadic at best. Maintaining the status quo in STEM educational practices will only exacerbate the disparities in STEM outcomes. Intersecting the domains of science/technology and art/design is important. Each domain has its role in multidisciplinary STEAM education and a deep overlap can exist and give rise to the concept of the unicorn, or individuals with a balance of technical expertise and artistic or creative flair who can tap into rewarding career and personal growth opportunities. The current STEM struggles will continue until the educational system hires people who are the pedagogical and technical/creative equivalent of a unicorn. The teachers must band together and be granted the autonomy to design/engineer their own content modules and be entrusted to deliver a product that ultimately supersedes the state testing standards. The thrust remains a challenge due to that lack of adoption at the state level. It is important for teachers to preclude any sense of a complacent teaching style or delivering boring content in the classroom; similarly, mitigating student boredom or apathy. Multiple “systemic” issues and shortcomings must be addressed that fundamentally, point to the need for prioritizing education for everyone regardless of privilege, class, wealth, and power. Without taking more aggressive steps to address the systemic issues, the students will suffer, and the lack of action will contribute to a greater societal concern—middle class erosion as a socioeconomic issue—further widening the STEM gap.

FQ10. Math Phobia: Understanding the link between math anxiety and STEM engagement is paramount. A possible reason for math anxiety/phobia is a less than student-friendly curriculum combined with a fear of failing the state Regents tests. Some students feel “defeated” from the start and early on seek to drop a class that requires the application of math skills. The teachers willingly intervene to help students overcome negative attitudes about math and take steps to empower and engage them, dispel their worries, build self-confidence and self-belief, and encourage them to keep trying. However, the teachers find it difficult to sustain engagement in some cases. Coping with failure is at the heart of the math anxiety issue. Teachers face the ordeal of undoing a legacy of anxiety seeded in the elementary/middle school level that urged the students to “get the math.” The incoming high school students arrive with an intrinsic apprehension of math and immediately erect walls that limit their capacity to advance and succeed in STEM. The incoming anxiety over math naturally creates a challenge for the high school STEM teachers who believe the students have the capacity to be successful, but where the students are less self-driven because of their fears. Elementary/middle school staff training in
confidence building should be conducted to help teachers and younger students see math, failure, and persistence through a new and different lens. Steps should be taken to avert surrender just because a concept was not grasped, or the correct answer not found on the first attempt. The teachers frequently work with the students to help them understand that failure is a good teacher. Persevering to localize mistakes involves critical thinking and realizing the moment of knowledge discovery, then reflecting on the process to reinforce learning. The teachers act as role models in this respect. Also, the students’ dependence on tools and electronic aids to accomplish basic mathematical tasks has been another challenge. Access to information and aids anytime, anywhere has led to instant gratification. By limiting their use, a sharp drop in the student’s comfort level and confidence can occur allowing for fear, defeat, and disengagement to take over. Reorientation training should be implemented to reinforce intrinsic math skills without the use of tools and electronic aids. The abstract nature of math is another STEM gap factor where steps should be taken to show math’s relevance to real-world applications that teach students important life skills. Unfortunately, the teachers are limited on this front because of their obligation to prioritize efforts towards preparing students for the state Regents tests. The teachers felt strongly about reforming the role of state testing standards in view of this concern. Instant gratification combined with a culture of state testing standards and grading criteria conspire in contributing to the STEM gap.

FQ11. Female Engagement/Persistence: The outcomes on female STEM engagement at ESM High School are mixed; on one hand, a substantial increase is seen in females applying for college STEM majors compared to 5 years ago while on the other hand, the opposite has been observed by some teachers citing the struggle to engage females in STEM. Uncertainty exists regarding ongoing and future trends. Anecdotally, female participation in STEM is seen to track with surges in technological advancements over time. Academic institutions are also making concerted efforts to recruit, retain, and support females in STEM fields. The teachers outreach to (female) students to dispel gender bias stereotyping while nurturing opportunities and cultivating self-efficacy regarding their STEM pursuits. The teachers explicitly foster associations between strength and empowerment and being a female in STEM. It is important to expose females to STEM at a young age to establish a foundation to build upon in their later years. More work is needed to engage females in STEM by breaking down the gender-bias stereotypes. Another view is that the STEM movement may be perpetuating a myth in the sense of an artificial need for females in STEM. The pressure on females to engage in STEM can backfire by discouraging them from naturally and freely choosing fields or professions that they want to pursue. The STEM community’s expectations may be too impractical, idealistic, or inflated when it comes to female engagement. Choosing STEM should be about an individual’s passion, talent, fit, and choice. It should be about moving past the stereotypes and not being driven to fill an “artificial” quota. Although many highly favor recruiting females in STEM fields, others are upset by the constant barrage of marketing on that front. Another gap contributor in female STEM engagement deals with the tact used by teachers, referring to female empowerment in choosing what they want to do, become, or pursue. Instead of questioning or challenging their choices, a better approach is to nurture, guide, and expose them to opportunities and options to help them make informed decisions in pursuing STEM or any other field of interest. A social injustice arises, and doubt is cast when females are questioned about their choices when it comes to STEM. Furthermore, the “STEM for girls” message can have a polarizing effect on STEM attitudes and is part of the problem. Although this type of message advocates for female involvement in STEM, it can backfire. Next, concerns exist over federal legislation that mandates large technology companies meet hiring quotas across, gender, race/ethnicity, and other socioeconomic and sociocultural criteria. The approach could also backfire by creating conditions that lead to the hiring of unqualified candidates and causing “workforce tensions,” rather than hiring based on talent and capability. Workforce tensions refer to an imbalance in workforce supply and demand of certain types of skilled labor that could be difficult to fill, thus potentially adding to the STEM pipeline gap. This is part of an ill-conceived process that sets itself up for failure because it neglects the science and the labor force data to launch a truly informed campaign.
**Research Question (RQ#)**

**Relevant Focus Group Questions (FQ#), A Priori Dimensions, and Study Findings**

**FQ12. Disadvantaged/Underserved Engagement:** Many of the issues identified for women apply to outreach and capture efforts for virtually any disadvantaged, underrepresented, or underserved groups. In addition to the gender-bias gap issue, socioeconomic factors should be more closely examined. The relevant socioeconomic issues and contributing factors are tied to federal and state legislation. Socioeconomics outweigh the gender-bias issue in terms of a greater number of class and race issue that such groups continue to face. No solutions above and beyond those identified for the female groups are identified or articulated at the present time.

**RQ4:** From the perspective of (students and) educators, how can interest in pursuing a STEM major in college or a STEM career be increased? Answered by FQ13 – FQ16.

**FQ13. In-class vs. Outside Class Learning:** Outside-class or cocurricular activities including clubs are clearly preferred over a traditional STEM classroom setting because they are less formal, unstructured, nonhierarchical, and non-imposing. The students and teachers are better able to connect, interact, and communicate with each other, thus building relationships that effectively translate to the classroom. The students are more able to explore, ask questions, and express their interests. The key outcomes are success in building relationships and expanding awareness of multidisciplinary connections in a natural context that ultimately benefits the classroom environment. Such experiences better enable career decisions through enhanced awareness. The importance emerged of having an environment for autonomy or the freedom to learn coupled with internships that builds confidence through natural and practical learning. Facilitating opportunities for learning outside of the classroom along with arranging internships at technology-based businesses allows for up front and close exposure to the various facets of STEM “in action, in the field.” The ESM High School sponsored opportunities for STEM learning in real-world settings are improving but remain limited. Another viewpoint recognizes the need to unleash the students’ fundamental desire for knowledge and how to apply it, or the notion of balancing theory and research against practical experience and applied theory. The belief is that the most effective learning experience is the one outside the classroom and by far, the students clearly prefer and benefit most from the outside learning experience. The teachers reaffirmed their skepticism of the student group/collaborative process that have been shown to be unproductive. From an in-classroom perspective, what is found to work is a project/goal-based learning model using a facilitator tier to assist the students across multiple projects and giving the students “ownership” of their individual projects. The modified group approach is different from the traditional classroom-group style of teaching and more in line with outside or cocurricular STEM learning environments. An alternate viewpoint considers the approach to be less about ownership and more about the students being engaged and invested in their project outcomes. Allowing for that perspective, a positive change is anticipated regarding how the group interactions unfold where successful group dynamics will depend on the group makeup and the nature of the project. If the students are open-minded and engage in a meaningful, purposeful project in-class or outside the classroom, they will be more willing to invest in the process with successful outcomes. The success of the STEM project-goal-based approach for in-class versus outside class environments depends on student “buy-in” or how they plan for successful outcomes. The students should be challenged to figure things out on their own and witness the outcome of applying their problem-solving skills, to expect some outcomes to be better and others, and to be prepared to manage failure. The teachers and facilitators should provide some guidance but not much “hand holding” in the process; assuming the students are serious and invested, they will try hard to achieve positive results because they do not want to fail. The strategy takes the students out of their comfort zone, engages them while instilling a level of confidence that they can achieve results regardless of the outcome, and keeps them focused by eliminating unnecessary distractions. Nonintuitively, placing them in a less rigid environment outside the classroom facilitates this type of learning environment or style.

**FQ14. Small-group Collaboration Benefits:** Reiterated is the need to give the high school STEM students individual discretionary time before engaging in any group collaboration. Once they have the
time to formulate their position and ideas, group or partner sharing can occur and a “growth” experience through dialogue can unfold. The approach (a) creates a “safe space” for individualistic concept development and to prepare for the group activity, (b) enables a process for (small) group interactions and the vetting and adoption of individual ideas, (c) protects individualism while allowing others an opportunity to identify with an idea, (d) offers students “membership” in a classroom group culture to hasten personal growth, and (e) teaches students team dynamics as a career building tool. Further underscored are the benefits of vetting ideas with multiple individuals and diverse viewpoints and the morphing of ideas within a group; learning collaborative and democratic processes; and converting the “individual” mindset into a “group dynamic” mindset. Also stressed is the importance of (small) group culture, teamwork, and communication in eliciting feedback from group members. The reality is that small group collaboration at ESM High School is often dysfunctional and where students demonstrate a lack of self-initiative. Small groups are effective when the students are taught how to interact, be open-minded, and risk discourse. Unfortunately, many students do not comprehend or think they need the soft (social) skills considered important for effective communication and group interaction, which are characteristic of industry integrated product team environments. Notwithstanding, a small group collaborative is considered beneficial because of the chance for one-to-one interactions and relationship building, but potentially disadvantageous because of the lack of diversity and the smaller chance of cross-fertilizing concepts or ideas. Requiring that students interact in small groups can be a foreign concept to them. If someone thrives and produces their best results independently, then it is senseless to deny them the opportunity; yet they should remain open to the idea of group sharing. Another aspect of small group collaboration is the concept of group “mix.” Small group dynamics and collaborative outcomes are not only influenced by the type of people in the group, the size of the group, and the subject or project under consideration; the group mix or makeup also plays a crucial role. State testing standards and Regents exams point to another group collaboration issue—that of small classroom review groups aimed at students passing the state tests and exams. The prior arguments for eliminating the Regents exams altogether applies here as part of a strategy to mitigate the STEM gap.

FQ15. Social Justice Factors: Some STEM fields are more competitive than others and combined with socioeconomic or sociocultural factors, create barriers to entry. On the other hand, STEM enables pathways for competitive skills development in fields that engender social justice and social equality touchpoints. Such STEM-related fields have seen growth in recent years from virtually all segments of society. Concerns remain however, over the future of the broader STEM landscape on the social justice front. STEM and a support system for nurturing the desired skill sets would be at the heart of an expanding ecosystem of opportunities to serve affected social groups. Females are an underserved, underrepresented demographic group in the STEM fields and are central to the social inequality issue. The dearth of females in STEM fields is an immediate, readily identifiable “symptom” that conveniently and frequently comes to the forefront. The debate over social inequality in STEM reduces to a one-sided issue explicitly skewed towards females and where males are implicitly overlooked in the argument; however, this raises another social injustice issue. Although STEM fields are male-dominated, the gaps are not strictly or even largely due to gender-specific factors. Indeed, the reasons for the STEM gaps go far beyond the issues of gender bias. The intent is to democratize STEM for everyone, to maintain a fair and level playing field, and to not force the STEM agenda in favor of one demographic over another. Individuals should be allowed to make their own choices regarding a field of study or career path, but certainly more can be done to show the opportunities and the paths forward to anyone regardless of gender or socioeconomic or sociocultural status. A side issue worth considering calls on using STEM as a tool to “remedy” ill-posed political messaging. The message and/or its delivery could disservice or disenfranchise certain social groups.

FQ16. STEM Thought Leadership: Teachers are aware of the disconnection among the STEM subjects and between STEM and non-STEM subjects that perpetuates siloed learning. STEM students who are largely exposed to a siloed learning environment will likely experience a “rude awakening” by the time
they enter college. A call for a shift in educational approach will further break down legacy siloed learning. STEM and the humanities should be formally integrated and taught together under the curriculum, and the teachers across multiple disciplines should find ways of collaborating more closely and effectively. STEM education was considered as important as education in the humanities for all students. All disciplines and teachers should be better “integrated” into STEM and to work together for the benefit of student engagement. Teaching about the connections across disciplines along with explanations and examples is an important goal and a necessary next step. A tighter connection is needed between math education and other disciplines. The teachers understand the merit of applying math to a variety of non-STEM subjects and vocational trade classes. The concept of STEAM as an integrated, multidisciplinary STEM-based approach that draws on non-STEM subjects, needs to be fortified and clarified. Just adding in the “what” is not the answer; it must be about the specific “what,” “why,” and “how”. Nonetheless, without a substantial shift in educational approach, engagement issues and gaps will continue to persist or worsen. The ESM High School teachers are well positioned to help fill the gaps. Their frontline experiences have revealed effective strategies for integrated, multidisciplinary education in STEM and other areas. A need exists for STEM curriculum reform at the state and district levels. Successful programs have been proven elsewhere to be viable and effective in driving change and filling the STEM gap that emerges between the high school senior year and the college freshman semester. Another contributor to the STEM gap is the college institution itself which can intentionally or inadvertently promote an image of elitism and a culture of inequity that can lead to disenfranchisement. The STEM gap can be filled by implementing, monitoring, and refining a real, well-crafted plan for full impact and measure instead of a superficial one that barely moves the needle on progress. Closer attention must be paid to the factors that fail to prepare students for college and that generally contribute to the STEM gap. If unprepared for the college-level experience and the rigors of multidisciplinary group STEM learning, the students may become disillusioned and eventually switch majors or drop out of college. It is incumbent on colleges to “actively” determine corrective measures to ensure that the student is successful in the program or has a viable alternative. The lessons learned can be used to advise the high school institution of the causes and effects at the secondary level that contribute to STEM disengagement. Recommendations are provided for keeping high school students in the STEM pipeline, who may be unsure about their fit or level of commitment as they enter college. Also, counselors have traditionally played a pivotal role in guiding a student’s career decision, but their role in this regard has shifted significantly. The school counselor’s role has become more about handling social-emotional issues; informed career guidance has become less of a priority, thus adding to the STEM gap. The STEM teachers have now taken on the role and the major responsibility of STEM career counseling for students they know or teach, but concerns exist over other students who are outside the STEM teachers’ spheres of influence. The combined lack of informed, engaged career counselors and the absence of reliable, consistent, and informed STEM career guidance for students is a significant contributor to the STEM gap. The students’ lack of direction as a factor in STEM disengagement is also considered from the teacher as a counselor perspective. The myriad electives, lack of direction given to teachers, sporadic coordination between administration and teachers, and the resultant distractions have exacerbated the situation to the point where guidance is incomplete, uninformed, or disjointed. The teachers are not always fully prepared or trained to give such counseling. ESM High School’s adult-teacher-driven focus could further explain some of the disconnects in STEM paths for students following high school. If the encouragement toward STEM is weak or sporadic, then engagement suffers. A beneficial approach is to engage core teachers across STEM, history, and language disciplines and strive to affect change through improved multidisciplinary education coupled with informed career counseling. The teachers’ experiences in multidisciplinary synergies have only scratched the surface but have been positive to date and hinted at much promise in the future. Finally, eliminating state standards testing and especially the state Regents exams should be seriously examined. The exams are viewed as detrimental to the STEM and STEAM agendas and a disservice to students on a wide scale. Many policy reforms in STEM education are needed before true change can take place and the benefits can be realized.