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# Modeling Successful STEM High Schools in the United States: An Ecology Framework

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## Abstract

This study aims to generate a conceptual framework for specialized Science, Technology, Engineering, and Mathematics (STEM) schools. To do so, we focused on literature and found specialized STEM schools have existed for over 100 years and recently expanded nationwide. The current perception for these schools can be described as unique environments including advanced curriculum, expert teachers, and opportunities for internships and immersion. Researchers have categorized these schools with three types: (a) selective STEM schools, (b) inclusive STEM schools, and (c) schools with STEM-focused career and technical education (CTE). Finding from the studies exploring college and career readiness of students attending these schools revealed students from specialized STEM schools are performing slightly better on high-stake mathematics and science tests in comparison with students in traditional schools. Studies also showed students from specialized STEM schools are more interested in STEM, more willing to attend classes, more likely to pass state tests, and more likely to earn college degrees. After synthesizing the literature, we created a conceptual framework of effective learning environments for specialized STEM schools using an ecology metaphor. This framework included actors (students, teachers, community leaders, and role models), contextual factors (learning environments, curriculum, instructional strategies, advanced coursework, and technology use), and actions (teaching, learning, immersion, communication, partnering, mentoring, support, and assessment).

**Key words:** STEM, STEM education, Specialized STEM schools, Learning environments.

## Introduction

In the current global economy, knowledge in science, technology, engineering, and mathematics (STEM) fields has become a central issue in the creation of many occupations (National Research Council [NRC], 2011). This issue is expected to continue well into the future. Historically, between the years 1950 and 2009, the average annual growth rate in the United States (U.S.) for science and engineering (S&E) occupations was 5.9%, whereas the total workforce grew by only 1.2% (National Science Foundation [NSF], 2012). However, education systems in the U.S. fall short in preparing students for occupations requiring STEM knowledge. The authors of the report *Successful K-12 STEM Education* suggest students in the U.S. do not possess high levels of STEM knowledge before accepting S&E occupations (NRC, 2011).

According to results from the National Assessment of Educational Progress (NAEP; Rampey, Dion, & Donahue) in 2009, 33% of U.S. 4th graders and only 26% of U.S. 8th graders were proficient in mathematics. These percentages do exhibit an increase from 1996 results, when the percentages were only 19 and 20, respectively (Schmidt, 2011). Although percentages from 2009 show growth, almost three out of four students still complete 8th grade without exhibiting proficiency in mathematics (NRC, 2011). Consequently, the current state of STEM education in the U.S.'s secondary and postsecondary education institutions may negatively impact the future U.S. economy. Responses by policymakers in the U.S. to national and international indicators, such as the NRC report mentioned above, point to the development of new strategies for increasing the number of students interested in S&E occupations, especially those students from historically underrepresented populations (i.e., female, diverse, and disabled).

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The report from the President's Council of Advisors on Science and Technology (PCAST) emphasized the potential for *specialized STEM schools* to serve as unique national resources which may have a direct impact on students while also closing the gap in STEM learning opportunities for historically underrepresented student populations (Lynch, Behrend, Burton, & Means, 2013; Navruz, Erdogan, Bicer, A., Capraro, & Capraro, 2014; PCAST, 2010).

This theoretical study presents a discussion on the research regarding students from specialized STEM schools. We focus on the historical background of these schools, learning environments found within their walls, demographic characteristics of students attending these schools, and the college readiness of those students (NRC, 2011). These foci translate into the following questions, which also emerged in Lynch et al. (2013) study: (a) How are specialized STEM schools defined in the literature? (b) How do specialized STEM schools operate? (c) What are the common models for specialized STEM schools? (d) Who benefits from attending specialized STEM schools? (e) What are the critical design components of specialized STEM schools? (f) How consistent and in what ways are their goals actualized?

The significance of this theoretical study refers to common goals expressing the need for attention to the preparation of students in STEM (Corlu, Capraro, & Capraro, 2014; Lynch et al. 2013; NRC, 2011; PCAST, 2010). A goal of many reports from the NRC and other governmental organizations is to generate better understanding of the background for specialized STEM schools. For this goal, the NRC (2013) identified indicators that form a national system for monitoring STEM education in the U.S. relevant to improve STEM education at both the state and national levels. In addition to understanding the background for specialized STEM schools, another goal in STEM education relates to the identification of components for effective learning environments. Lynch et al. (2013) hypothesized specialized STEM schools do more than merely focus on STEM disciplines or integrate new technologies. Therefore, identifying the critical components of specialized STEM schools should help to create effective learning environments for producing graduates prepared for STEM related careers. To assist in identifying these components, we present a conceptual framework at the end of this study modeling an effective learning environment for specialized STEM schools.

A third goal in STEM education requiring attention relates to describing the demographics of students who benefit from attendance at specialized STEM schools (Cole & Espinoza, 2008; Erdogan, Corlu, & Capraro, 2013; Rogers-Chapman, 2013; Tyson, Lee, Borman, & Hanson, 2007). Recently, the U.S. Department of Commerce (2011) projected an increase in S&E occupations for the next 5 years. The National Science Foundation (2012), however, has indicated the U.S. is not producing enough graduates of any demographic background to fill these occupations. The NSF (2013) also highlighted the disproportionate dispersion of S&E occupations across ethnicity and gender demographics (Table 1). These statistics emphasize the importance of considering students' demographics in specialized STEM schools to better understand how to improve STEM education.

Table 1. Cross Distribution of Ethnicity and Gender for U.S. Citizens in S&E Occupations During 2010

| | Gender | |
|---|---|---|
| Ethnicity | Female (%) | Male (%) |
| White | 18.0 | 51.0 |
| African American | 2.0 | 3.0 |
| Hispanic | 2.0 | 4.0 |
| Asian | 5.0 | 13.0 |
| Other | 1.0 | 1.0 |
| Total | 28.0 | 72.0 |

*Note*. The Other ethnicity includes American Indian or Alaska Native, Native Hawaiian or Other Pacific Islander, and multiple races.

A fourth goal in STEM education requiring attention relates to characteristics of specialized STEM schools (Means, House, Young, Wang, & Lynch, 2013; Tyson et al., 2007; Young et al., 2011). These characteristics are vital to preparing students for college experiences. Tyson et al. (2007) discussed the importance of understanding course-taking patterns among students in specialized STEM schools and the influence of these patterns on students' participation in STEM learning. In addition, Means et al. (2013) indicated a significant influence of students' academic backgrounds on their decisions to remain in STEM courses. Young et al. (2011) investigated how Inclusive STEM High Schools (ISHS) performed in comparison to other high schools. These studies indicate a need to identify the characteristics of successful specialized STEM schools to better understand STEM education.

## Background of Specialized STEM Schools

While specialized STEM schools are at the peak of current research interest, these schools have existed for over 100 years. The body of literature addressing STEM schools has historically used the name "specialized Science, Mathematics, and Technology (SMT) schools" (Olszewski-Kubilius, 2010; Subotnik, Tai, Rickoff, & Almarode, 2010; Thomas & Williams, 2010). The very first examples of these schools were founded in New York City during the early part of the 20th century in US.

### The Beginning of Specialized STEM Schools

The early attempts for specialized STEM schools aimed raising skilled workers for specific industrial areas. In 1904, Stuyvesant High School became the first specialized SMT school (Thomas & Williams, 2010). This "manual training school for boys" was established for the development of talent in science, mathematics, and technology. In 1969, Stuyvesant High School began to accept girls for the first time. Currently, 43% of the students at this school are girls (Stuyvesant High School, 2013). Brooklyn Technical High School opened in 1922 to serve students in the Brooklyn borough of New York City (Thomas & Williams, 2010). The purpose of this specialized SMT school was to provide courses in science, mathematics, drafting, and shops, for students choosing to attend college or begin technical careers. In 1970, female students began to first enroll in Brooklyn Technical High School (Brooklyn Technical High School, 2013). The Bronx High School of Science, another specialized SMT school in New York City, was founded in 1938 (Thomas & Williams, 2010). Again, the emphasis of this school was on science and mathematics education for preparing technically trained students. In 1946, The Bronx High School of Science became co-ed to provide equal opportunities for female students (The Bronx High School of Science, 2013).

### Evolution of Specialized STEM Schools

National policymakers in the U.S. during the latter half of the 20th century placed more emphasis on STEM education after the launch of Sputnik (Gardner, 1983). Concurrently, state policymakers created more SMT schools through statewide initiatives (Stephens, 1999). One of the first state initiatives to emerge at this time was a residential summer program for gifted students in North Carolina. In 1980, this program was transformed into a residential specialized SMT school taking the name The North Carolina School of Science and Mathematics (Pfeiffer, Overstreet, & Park, 2010). Over time, each U.S. state has made similar progress in founding a residential specialized SMT school for highly capable students (Pfeiffer et al., 2010; Stanley, 1987). In 1988, a number of SMT schools came together to establish the National Consortium for Specialized Secondary Schools of Mathematics, Science, and Technology (NCSSSMST; Olszewski-Kubilius, 2010; Thomas & Williams, 2010). The eleven founding schools – with year of opening in parenthetical – included:

- Illinois Mathematics and Science Academy (1986),
- Louisiana School for Math, Science, and the Arts (1983),
- Montgomery Blair High School (1985),
- Eleanor Roosevelt Science and Technology Center (1976),
- Mississippi School for Mathematics and Science (1987),
- North Carolina School of Science and Mathematics (1980),
- Liberal Arts and Science Academy High School of Austin (1985),
- Central Virginia Governor's School for Science and Technology (1985),
- New Horizons Governor's School for Science and Technology (1985),
- Roanoke Valley Governor's School for Science and Technology (1985), and
- Thomas Jefferson High School for Science and Technology (1985; NCSSSMST, 2013).

The NCSSSMST was founded to function as a catalyst for advancing STEM education. By providing students, teachers, and communities with the means to achieve in a technology driven society, the NCSSSMST meets the overall mission of the consortium: (a) preparing students for success and leadership in STEM, (b) scaffolding communication and collaboration between member schools, (c) transmitting information about current developments in STEM education, and (d) expanding efforts for advanced STEM education (NCSSSMST, 2013). Currently, the NCSSSMST serves over 39,000 students and 1,600 educators in almost 100 institutions. Together, these individuals and institutions work with people in over 55 additional affiliate institutions (e.g., universities, companies, and educational centers; NCSSSMST, 2013; Thomas & Williams, 2010).

The evolution of STEM education in the last century also included a transition from "manual training schools" to "specialized SMT schools". In the late 20th and early 21st centuries, additional schools took the name "specialized STEM schools." These schools were often created through state and national initiatives designed to address concerns over U.S. economic competitiveness and the perceived shortage in the STEM workforce. The current perception of most education leaders, policymakers, and researchers for specialized STEM schools can be described as follows:

> …[Specialized STEM schools] offer a unique and comprehensive environment—one that includes an advanced curriculum and opportunities for significant immersion in the work of the field through mentorships, internships, and research apprenticeships that are often beyond what is available in even the best high schools; a faculty with exceptionally high levels of content area expertise, often consisting of doctorates in content areas; and a select population of students who are homogeneous with respect to ability levels, interests, and aspirations. (Olszewski-Kubilius, 2010, pp. 61-62)

## General Characteristics of Specialized STEM Schools

Characteristics of specialized STEM schools vary depending on the context and location of schools. However, most of these schools accept students after a sophomore year of high school experience. Admission into these schools is often selective and based on a set of criteria including: (a) standardized test scores, (b) essays, (c) portfolios, (d) references, and (e) interviews (Kolloff, 2003; Olszewski-Kubilius, 2010; Sayler, 2006). The student populations in these schools may be diverse, reflecting the demographic background of the student population found within the school's home state. In addition, student populations within these schools are often homogenous in terms of interest in STEM courses (Kolloff, 2003); including Advance Placement (AP) and International Baccalaureate (IB; see Kolloff, 2003; Olszewski-Kubilius, 2010; Sayler, 2006). Many of these schools also encourage students to participate in national and international science fairs and Olympiads. Another opportunity or requirement in some schools is the integration of internships occurring in the business community outside of the school. Internships in this context can be described as any type of service that has certain learning goals related to STEM. Each of these general characteristics for specialized STEM schools has evolved over time until becoming common for most schools (Kolloff, 2003; Olszewski-Kubilius, 2010; Sayler, 2006).

### Curriculum in Specialized STEM Schools

Pfeiffer et al. (2010) examined how specialized STEM schools incorporate content into curriculum. Results of their study with 16 participating schools indicated specialized STEM schools were likely to offer research opportunities for students. Students in 15 of the 16 schools conducted research with a faculty member or a mentor and students in 13 schools continued their research throughout summers with the assistance of a mentor. Also, students in 12 schools conducted their own research using either a laboratory or off-campus facility. Not surprisingly, students in 11 schools participated in contests to disseminate results of research. Of the 16 schools, administrators in six indicated the incorporation of STEM content with the humanities curriculum. While administrators in 13 schools identified a minimum number of mathematics courses for students, only seven of 16 schools required a minimum number of science courses. However, the average number of science courses offered by these schools was 34 and the average number of mathematics courses was 21.

### Instructional Practices in Specialized STEM Schools

The transformation of specialized STEM schools over the last century has changed many learning goals for students. One exception, however, includes the goal of creating students who are experts in science (Bransford, Brown, & Cocking, 2000). To produce these experts, educators should develop instructional practices organized around meaningful and appropriate learning goals. These instructional practices should result in two abilities for students; applicability of prior knowledge and mastery of domain knowledge (Goldman, Petrosino, & Cognition and Technology Group at Vanderbilt, 1999). The *How People Learn* framework approaches instructional practices using four –centered perspectives: (a) learner, (b) knowledge, (c) assessment, and (d) community. In learner-centered environments, students establish both conceptual and cultural knowledge; whereas, in knowledge-centered environments, students make sense of learned content. In assessment-centered environments, students receive feedback from experts. Finally, in community-centered environments, students learn from other members of a group (Bransford, Brown, & Cocking, 2000). Instantiating the *How People Learn* framework to set an example, Minstrell, Anderson, and Li (2011) created a framework by embedding assessment within the teaching and learning cycle. Building on Learner Thinking (BOLT) is the conceptualization of assessment and instruction as an ongoing process (see Figure 1). In this figure, boxes represent ideas while circles represent learning experiences. Also, lines between the boxes and circles represent ongoing interactions. Numbers on the lines are only for reference and do not represent a certain order of interactions.

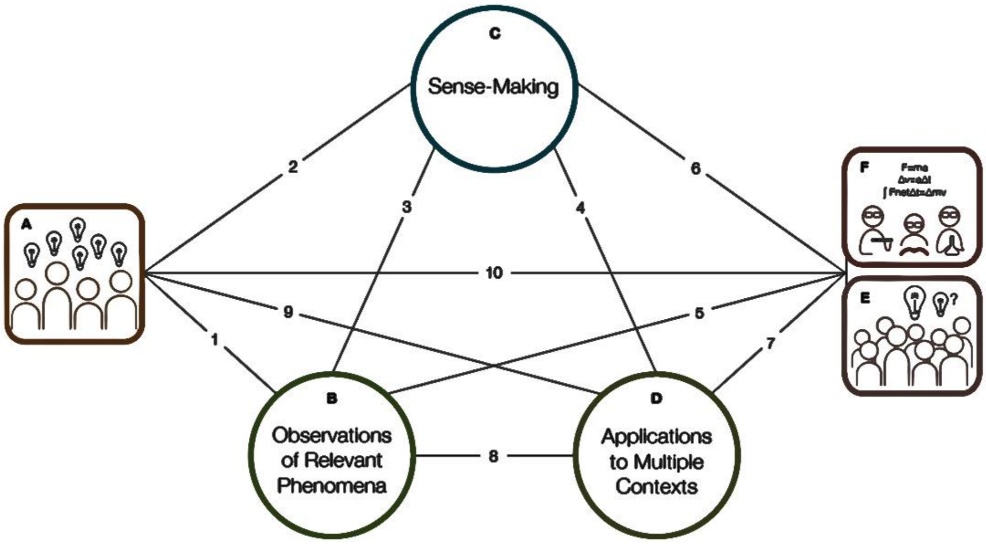


Figure 1. Diagram of the BOLT framework (Minstrell et al., 2011, p. 4).

In box A, students start instruction by brainstorming to identify initial ideas and hypotheses. In this process, teachers should address the failing ideas immediately; otherwise, these failing ideas may continue to exist. In box F, scientists' ideas appear to set learning goals for students. In box E, students determine shared ideas and identify those shared ideas which are similar to the scientists' ideas. In circle B, students collect and interpret data to test shared ideas. In circle C, students connect prior knowledge with inferred knowledge from data. In circle D, students find opportunities in different contexts to implement or generalize what they learned (Minstrell et al., 2011). Ongoing interactions represented by the lines are questions driven by the activities and the discourse in the classroom. As an example, lines 2 and 3 represent interactions between students' initial ideas (A), collected data (B), and inferences or explanations (C). Line number 4 represents the similarities and differences between students' inferences or explanation (C) and implementation or generalization of phenomena (D). In order to fully implement the BOLT framework, students and teacher should create a culture of learning. In addition, a strong example of implementation requires establishing more relationships between learning experiences (i.e., boxes and circles; Minstrell et al., 2011).

## Types of Specialized STEM Schools

Researchers have categorized specialized STEM schools using characteristics of different school models (Subotnik et al., 2011). The NRC (2011) categorized these schools using students' outcomes and admission criteria into three types of schools: (a) selective STEM schools, (b) inclusive STEM schools, and (c) schools with STEM-focused career and technical education (CTE). The following discussion elaborates these categories.

### Selective STEM Schools

Selective STEM schools focus on one or more STEM disciplines. Students enrolled in these schools are selected based on a set of criteria including academic achievement. Therefore, students in selective STEM schools are highly talented, motivated, and interested in STEM. Selective STEM schools incorporate expert teachers, rigorous curricula, advanced laboratory and other resources, mentorships, and improvement opportunities for their teachers (i.e., professional development workshops). NCSSSMST's member schools are examples of selective STEM schools (NRC, 2011; Subotnik et al., 2011).

Subotnik and colleagues (2011) approached selective STEM schools from a deeper perspective, focusing on characteristics unique to each school model rather than focusing on common characteristics. According to this study, selective STEM schools can be categorized under four headings: (a) state residential schools, (b) comprehensive schools, (c) schools-within-schools, and (d) half-day schools. State residential schools are selective schools run with state money; therefore, states stipulate that the student population in state residential schools represent every county. Comprehensive schools are also selective schools and are generally established in metropolitan areas to serve gifted students in a particular area. Schools-within-schools are established in urban areas and mostly serve gifted and historically underrepresented student groups with limited resources. Half-day schools are typically located in economically disadvantaged neighborhoods or rural areas and provide challenging coursework for gifted students of the region. Students are transported by busses to half-day STEM schools after they attended classes in their home schools (Subotnik et al., 2011).

### Inclusive STEM Schools

Inclusive STEM schools provide STEM education for a broad population of students. These students, regardless of past achievements, are eligible for admission at inclusive STEM schools. However, inclusive STEM schools are also designed especially for students from historically underrepresented groups. Students may choose to attend inclusive STEM schools for a number of reasons, including: safe environment, new technology, or college preparatory program (Lynch et al., 2013; NRC, 2011; Rogers-Chapman, 2013; Young et al., 2011). Inclusive STEM schools are known for having college preparatory curricula, small school sizes, expert teachers, and technology rich environment (NRC, 2011). Schools in Texas' STEM school initiative are examples of inclusive STEM schools.

### Schools with STEM-Focused Career and Technical Education (CTE)

Schools with STEM-focused CTE were established as support programs for students interested in STEM. These schools are usually located in educational centers, comprehensive high schools, or career academies. STEM-focused CTEs predominately focus on science, mathematics, and technology. Students usually attend these schools or programs for a half-day after attending a district designated school. Schools with STEM-focused CTE serve two primary purposes: prepare students for college and assist students at risk for dropping out of high school. To achieve these two purposes, schools with STEM-focused CTE offer students real-world applications of STEM education in the classroom (NRC, 2011; Stone III, 2011). Dozier-Libbey Medical High School is an example of a STEM-focused CTE. The school functions as a bridge between the high school and college learning environments while focusing on a practical science education. All students attending this school are required to take at least four science courses, four mathematics courses, and two years of foreign language. As a result, graduates of Dozier-Libbey Medical High School meet most of the course requirements for the University of California. In addition, school curricula are organized around the health sciences and project-based learning is chosen as the primary teaching strategy. Therefore, teachers and partnering organizations develop hands-on activities for instructional purposes. These activities include following an employee, guided site visiting, in-service experience, research projects, and internships (Dozier-Libbey Medical High School, 2013; NRC, 2011).

## Design Components for Successful Specialized STEM Schools

After transformation of SMT schools into specialized STEM schools, the perception among education leaders, policymakers, and researchers for these schools was developed as described by Olszewski-Kubilius (2010) above. However, the current status of specialized STEM schools is not seen as promising by some researchers (Lynch et al., 2013; Marshall, 2010). One common idea expressed by these researchers is that of a flawed design in U.S. schools show a disconnection between the needs and the expectations of the nation for an advanced STEM education. Significant changes in educational, technological, and economical contexts may cause the flawed design (Marshall, 2010). In response, researchers have suggested new design principles and conceptual frameworks necessary to create environments to inspire and attract a new generation of students (Lynch et al., 2013; Marshall, 2010).

Marshall (2010) argued learning environments designed to advance STEM education must help students in developing positive intellectual habits. These habits lead to new skills, such as creative thinking, problem solving, leadership, and innovation. These learning environments, hubs for transformation in STEM education, should work as systems in which students' innovations, talents, and leadership skills are nurtured. Marshall (2010) suggested a number of fundamental design principles should occur in successful specialized STEM schools. The nine principles Marshall suggested include: (a) creating a living ecosystem in which innovation, talent, and leadership dominate; (b) learning through a series of experiences; (c) personalizing the experience for every individual; (d) including community; (e) providing access to global commons such as digital technologies; (f) ensuring students master each STEM domain; (g) triggering integrative and trans-disciplinary thinking in students' minds; (h) including authentic curriculum, instruction, and assessment in the learning environment; and (i) making learning occur at the right time and place. Taken together, these principles should, according to Marshall, create successful specialized STEM schools.

Based on these nine design principles, Marshall (2010) created a conceptual framework for learning in specialized STEM schools. Her framework reimagined these schools to include three learning environments with an integrating hub. The first of the three learning environments centers on inquiry, research, and interdisciplinary learning. The second centers on innovation and design while the third centers on global leadership and social entrepreneurship. Each of these three learning environments intersects at an integrating hub Marshall refers to as the Leadership, Innovation, Knowledge (LINNK) Commons and Transformation Exchange. For Marshall, the LINNK provides a network for the larger academic community including students, mentors, leaders, and other STEM professionals. Her framework is one of many useful for describing specialized STEM schools.

Another framework proposed by Lynch et al. (2013) provides a broader perspective. Lynch and colleagues suggested a framework covering design dimensions as well as implementation practices and student outcomes. These researchers created a conceptual framework after determining not a single design existed for all specialized STEM schools. However, they did determine a shared set of components existing in all these schools. Lynch et al. (2013) identified ten shared components. These ten components include: (a) STEM-focused curriculum (Atkinson, Hugo, Lundgren, Shapiro, & Thomas, 2007; Brody, 2006; Lynch et al., 2013; Subotnik et al., 2010), (b) reform instructional strategies (Atkinson et al., 2007; Lynch et al., 2013; Subotnik et al., 2010), (c) integrated and innovative technology use (Atkinson et al., 2007; Lynch et al., 2013), (d) blended formal and informal learning (Lynch et al., 2013; PCAST, 2010), (e) real-world STEM partnerships (Atkinson et al., 2007; Brody, 2006; Lynch et al., 2013; Stone III, 2011; Subotnik et al., 2010), (f) early college-level coursework (Atkinson et al., 2007; Lynch et al., 2013), (g) well-prepared STEM teaching staff (Lynch et al., 2013; Subotnik et al., 2010), (h) inclusive STEM mission (Lynch et al., 2013; PCAST, 2010), (i) administrative structure (Lynch et al., 2013), and (j) support for underrepresented students (Lynch et al., 2013). According to Lynch and her colleagues (2013), these components are critical in creating specialized STEM schools, which are successful in assisting students' mastery of STEM knowledge. In developing these components, the authors began with a conceptual framework for specialized STEM schools patterned on ISHS. These schools were chosen due to their mission of serving historically underrepresented student populations.

The U.S. Department of Commerce's (2011) projections regarding opening job occupations related to STEM in this decade directed education leaders and policymakers to include minority groups, such as female or underrepresented ethnic groups, into the STEM pipeline. Their recommendation for education leaders and policymakers was to first understand the demographics of students attending specialized STEM schools (Rogers-Chapman, 2013). However, studies reporting genders, ethnicities, or socioeconomic levels of students attending specialized STEM schools are limited.

## Demographics of Students Attending Specialized STEM Schools

According to the NSF (2013), females constitute a small portion of the STEM workforce in the U.S. (see Table 1). However, females in the U.S. constitute half the population (Table 2). A recent study in STEM education suggested gender plays no role in students' learning; however, females are less likely to earn baccalaureate degrees related to STEM or continue in the STEM pipeline (Tyson et al., 2007). Additionally, a recent report indicated as much as half of 9th grade students enrolled in ISHS were female (Young et al., 2010).

Table 2. Cross Distribution of Ethnicity and Gender for U.S. Citizens During 2010

| | Gender | |
|---|---|---|
| Ethnicity | Female (%) | Male (%) |
| White | 32.3 | 31.3 |
| African American | 6.4 | 5.8 |
| Hispanic | 8.3 | 8.1 |
| Asian | 2.5 | 2.2 |
| Other | 1.6 | 1.5 |
| Total | 51.1 | 48.9 |

*Note*. The Other ethnicity includes American Indian or Alaska Native, Native Hawaiian or Other Pacific Islander, and multiple races.

NSF (2013) also reported the distribution of ethnicity for U.S. job occupations related to STEM, which were 69% for Whites, 5% for African Americans, 6% for Hispanics, 18% for Asians, and 2% for others (see Table 1). As indicated in the table, non-Whites are not represented adequately in job occupations related to STEM. In a study on ethnicity of students attending specialized STEM schools, the average percentage of White/Caucasian students enrolled in 15 residential STEM schools was 70% in 2008, while the percentages were 11% for African Americans, 3% for Hispanics, 14% for Asians, and 2% for Native Americans (Jones, 2010). Percentages from this study are very similar to those reported by the NSF in 2013. Another study exploring the STEM related achievement gap among different ethnic groups in high school reported African American and Hispanic students underperforming White and Asian students (Tyson et al., 2007).

Rogers-Chapman (2013) conducted a study on ethnicity and socioeconomic levels of students attending specialized STEM schools. Using Common Core Data from 2007, difference means test analyses indicated student populations in inclusive STEM schools was three times larger than populations in selective STEM schools. Researchers reporting on the 221 inclusive STEM schools found 33% of students were from the low socioeconomic status, while 40% of students were from the low socioeconomic status that attended one of the 52 selective STEM schools. However, the distribution of ethnicity for students in both school types was similar. For example, averages within inclusive STEM schools' population were 24% white, 45% African American, 20% Hispanic, 10% Asian, and 1% other students. Similarly, averages within selective STEM schools' population were 25% white, 41% African American, 29% Hispanic, 4% Asian, and 1% other students.

Overall, research results suggest students from historically underrepresented groups (i.e., female, African American, Hispanic, or low SES) earn STEM degrees at lower rates than students from highly represented groups (i.e., male, White, Asian, or high SES; Tyson et al., 2007). Disparities in earning STEM degrees go beyond student demographic characteristics. Other factors also include course taking opportunities and parental involvement (Cole & Espinoza, 2008; Griffith, 2010; Rogers-Chapman, 2013). Specialized STEM schools are designed to reduce the influence of students' demographic characteristics and other factors by providing equitable learning opportunities for all students (Lee, 2011). One question remains unanswered; do specialized STEM schools prepare students for college? In research, this preparation for students is described as college and career readiness.

## College and Career Readiness of Students Attending Specialized STEM Schools

In 2010, a blueprint for U.S. educational reform focused on college and career readiness of students. This blueprint resulted from 40% of college freshman students taking remedial courses (U.S. Department of Education, 2010). To address this issue and prepare all students for college and career, the U.S. federal government reauthorized the Elementary and Secondary Education Act (ESEA). Primary changes in the ESEA include (a) raised standards in English language arts and mathematics, (b) reformed assessments aligned with college and career readiness standards (CCRS), and (c) structured reward system for schools and districts. The blueprint for changes to the ESEA also suggested a support system, which would include (a) improved support for teachers through professional development workshops, (b) enriched instruction for less successful schools, and (c) increased flexibility for schools and districts. Finally, this blueprint suggested every state continue implementing science standards and assessments. Researchers have yet to determine if the changes made in the ESEA have prepared students for college and career.

In 2008, the Texas legislature passed the "Advancement of College Readiness in Curriculum" bill to increase the number of students ready for college and career (Educational Policy Improvement Center [EPIC], 2009). In accordance with the bill, a team of experienced educators and university faculty gathered to define new CCRS for English language arts, mathematics, science, and social studies courses. The purpose of new CCRS in Texas was to prepare students to succeed in college. These courses, designed according to CCRS, help students gain a set of core knowledge and skills, so that they can succeed in any chosen college major. According to authors of the CCRS, students actualizing each standard would be prepared for college and career.

The focus for the new generation of specialized STEM schools is to reduce disparities among underrepresented groups and prepare these students for college and career. Specialized STEM schools achieve this focus by: (a) admitting higher rates of students from historically underrepresented groups, (b) encouraging female students to participate in extracurricular activities related to STEM, and (c) cooperating with role models from historically underrepresented groups. Specialized STEM schools reflecting the focus of reducing disparities among historically underrepresented groups are described as inclusive STEM schools. Means et al. (2013)

compared the college-related interests of students attending inclusive STEM schools and traditional schools (i.e., public schools with no specific focus). Research findings from 1,719 9th graders in inclusive STEM schools and 3,359 in traditional schools suggested students from inclusive STEM schools are more interested in STEM subjects than students from traditional schools. These students (i.e., students from inclusive STEM schools) were also more confident about graduating from high school and earning a baccalaureate degree. Other differences between inclusive STEM schools and traditional high schools identified in the comparison indicated students from inclusive STEM schools enrolled in more college preparatory courses in STEM disciplines, showed more interest in graduate school education (44% and 33%, respectively), and were more likely to enroll as engineering majors in college (26% and 18%, respectively).

Findings from another study on students' achievement in the state of Texas showed students in 9th grade from T-STEM academies performed slightly better on the mathematics state test and 10th grade students performed better on both the mathematics and science state tests. However, effect sizes showed differences were not very big, ranging from 0.12 to 0.17. Also, 9th grade students in T-STEM academies were 1.8 times more likely to meet the benchmarks of Texas Assessment of Knowledge and Skills (TAKS) mathematics and reading comparing to other schools. Similarly, 10th graders in T-STEM academies were 1.5 times more likely to pass TAKS in all four domains. In addition, 9th grade students in T-STEM academies were 0.8 times less likely to be absent from school. For other grade levels, there were no statistically significant differences between students in T-STEM academies and comparison schools. All the findings in this study suggest students benefit from T-STEM academies in certain subjects instead of an overall improvement (Young et al., 2011).

In another study of schools in the NCSSSMST, 1,032 students in specialized STEM schools were followed post graduation (Thomas, 2000; Thomas & Love, 2002; Thomas & Williams, 2010). For all participants, 75% indicated a desire to continue education beyond high school and 40% planned to obtain a doctorate degree. 51% of students who graduated from specialized STEM schools pursued a science major in college. Results from this study suggested 10% of students who graduated from specialized STEM schools went on to major in mathematics. In addition, results of this study indicated 60% of college freshman participants expected to earn a STEM degree and 55% of college senior participants were about to earn a STEM degree (Thomas, 2000).

## Conceptual Framework for Specialized STEM Schools

Demographic studies confirm that a number of schools in the 21st century have focused on STEM disciplines. Many researchers in the last decade have studied these schools. These schools were first introduced by education leaders and policymakers at the beginning of 20th century (Thomas & Williams, 2010). Both groups (i.e., researchers as well as education leaders and policymakers) now express concern about the adequacy of existing specialized STEM schools meeting the needs of the U.S. workforce (U.S. Department of Commerce, 2011). Unfortunately, education leaders and policymakers differ with researchers on how to meet the needs of the workforce with future schools.

If the problem of adequacy is related to quantity, education leaders and policymakers believe opening (1000 schools) new specialized STEM schools would be an effective response (PCAST, 2010). Conversely, if the problem is related to quality, researchers believe increasing the quality of existing specialized STEM schools would be equally effective (Lynch et al., 2013). Regardless, the problem of adequacy is likely to persist. Mindful that each specialized STEM school should have a learning environment specific to itself, as stated at the beginning of this theoretical study, we synthesized the literature related to specialized STEM schools and conceptualized an effective learning environment for future directions of these schools.

In our conceptual framework, we modify Weaver-Hightower's (2008) ecology metaphor for learning environments. This ecological metaphor addresses learning environments as systems with components of actors, contextual factors, and actions working interdependently. As within natural systems in which living organisms interact among themselves; actors within school learning elements also interact among themselves. For example, students and teachers interact to achieve a common learning goal. In addition, contextual factors such as boundaries are facets of ecosystems in which actors perform actions. For example, classrooms are contextual factors for formal learning. Finally, actions in ecosystems such as cooperation are transferable in understanding the complex interactions among actors. For example, students cooperate in groups to finalize a project (Erdogan, Bozeman, & Stuessy, 2013).

As we identified in the Background of Specialized STEM Schools section, these schools were created by stakeholders (i.e., education leaders and policymakers) to address STEM education. However, in doing so, other stakeholders (i.e., researchers) claim these same schools have failed to address all STEM disciplines. This claim has led researchers to suggest new conceptual frameworks (Lynch et al., 2013; Marshall, 2010). These frameworks create environments, which contribute to students' outcomes. In this theoretical study, we combine components of specialized STEM schools into our conceptual framework. We name this conceptual framework "collaborative actions of community" (see Figure 2).

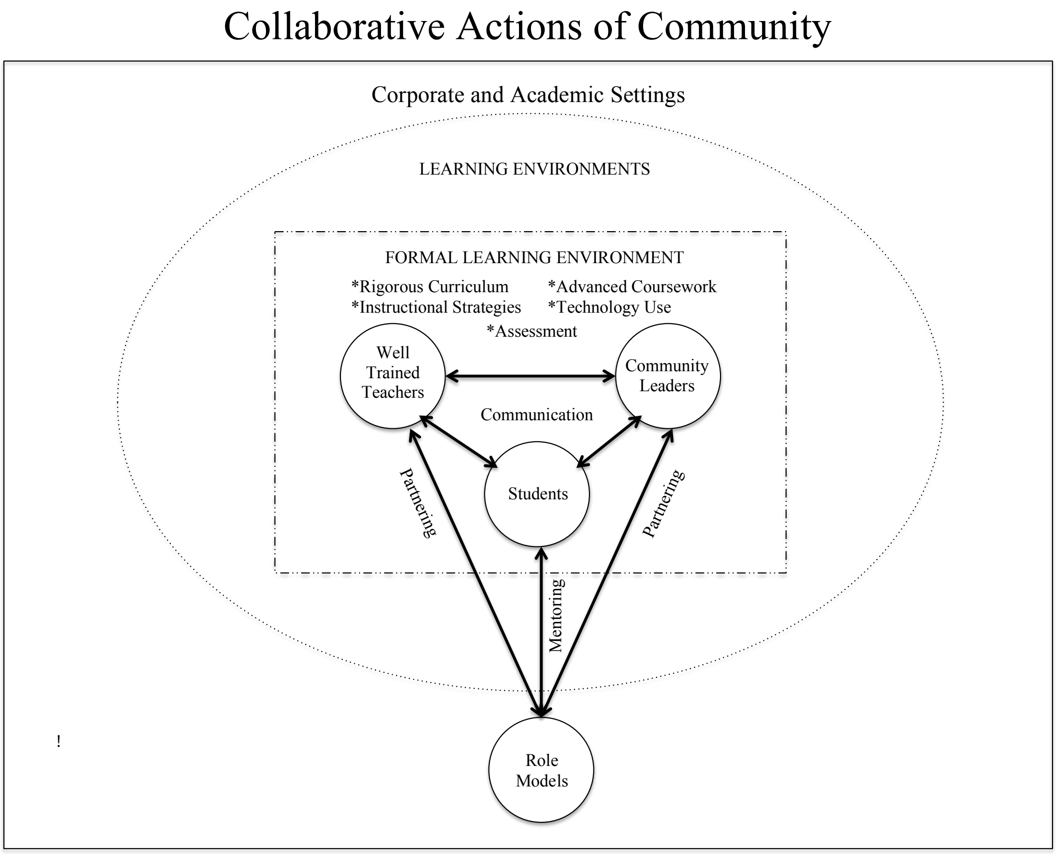


*Figure 2.* Conceptual framework of effective learning environments for specialized STEM schools.

In the school ecology framework, the components of specialized STEM schools can be grouped under three categories: (a) Actors, (b) Contextual Factors, and (c) Actions (Erdogan et al., 2013; Weaver-Hightower, 2008). These three categories in our framework constitute the skeletal structure of a specialized STEM school (Eisenhart, 1991). This framework, as a guide for establishing specialized STEM schools, can be read top-down. To better understand the conceptual framework, a closer look is necessary.

## Actors

Actors within an ecosystem play individual roles while also depending on others (Weaver-Hightower, 2008). In schools, as well, actors perform social roles in carrying out the process of education. Actors in this framework include students, teachers, community leaders, and role models (see Figure 2). Students serve as the primary actors in this framework whereas teachers, administrators, and other actors serve as support for the development of students. It should also be noted an actor can perform more than one role at a time (Weaver-Hightower, 2008). For example, teachers can teach students in the classroom and be trained by role models outside the classroom.

Students, as actors, are at the center of our school ecology framework (see Figure 2). Rallis (1995) indicated a learner-centered school provides students with the truest opportunities for asking questions and finding solutions under the supervision of teachers. This would suggest in such a school that curiosity would lead students to (a) pose questions, (b) make observations, (c) collect data, (d) interpret data, (e) take risks, (f) test conclusions, and (g) be creative. Teachers, in such a school, would be more flexible in tolerating students' mistakes from taking these opportunities. Finally, as this framework suggests, actors in a learner-centered school would be more likely to accept change but not likely to accept the status quo (Rallis, 1995).

Teachers, as actors, are another component in the framework (see Figure 2). Rallis, Rossman, Phlegar, and Abeille (1995) stated well-trained teachers in specialized STEM schools are expected to (a) master domain and instructional strategies, (b) dedicate themselves to teaching, (c) facilitate learning in the classroom, (d) challenge students' minds, (e) connect students with the community, (f) use technology effectively in the classroom, and (g) become school leaders. Teachers, in such a school, may be given opportunities to update knowledge and skills by attending professional development workshops. Finally, in this framework, actors are likely to accept teachers as the leaders of change (Rallis, 1995).

Other actors within the school ecology framework include community leaders (see Figure 2), which include, but are not limited to, student leaders, teacher leaders, staff, administrators, and parents. Community leaders form a unique school culture around meaningful goals and shared values to reach learning, reform, and achievement (Deal & Peterson, 1999). They also may link students, teachers, staff, administrators, parents, and other actors of the community. For a better learning environment, community leaders may especially encourage teachers to take responsibilities by (a) communicating, (b) supporting, (c) giving more power, (d) involving in decision-making process, and (e) appreciating them. When teachers take these responsibilities, they are likely to improve teaching and learning conditions, lead reforms, and exalt the profession of teaching (Barth, 1988). Finally, community leaders and teachers can be trained by or partner with other actors, role models who are another essential component of this framework.

Role models within the framework include, but are not limited to, university faculty members, technicians in labs, business or industry leaders, other STEM professionals, and parents (see Figure 2; Lynch et al., 2013). Role models may represent a motivational factor and guidance for students and teachers. Role models can interact with students and teachers via an internship or apprenticeship program regardless of school boundaries. Immersing students in a real life experience via internship with role models may be the most effective way to show the implementation of what they learn in classrooms. Immersion can also be beneficial to maintain students' interest in STEM and keep it as high as possible (Lee, 2011; Marshall, 2010; Subotnik et al., 2011). As well as actors, the contextual factors are important to fully grasp the school ecology framework.

**Contextual Factors**

Contextual factors within an ecosystem provide extant conditions (i.e., boundaries, pressures, inputs, and consumption; Weaver-Hightower, 2008). In schools, the primary contextual factors in our school ecology framework are the learning environments (see Figure 2). In specialized STEM schools, formal and informal learning environments should not be separated with certain boundaries. Instead, actors should use them in harmony (Lynch et al., 2013; Marshall, 2010; Subotnik et al., 2011). In the framework, a rectangular shape with dashed line was used to define formal learning environment and an elliptical shape with dashed line for informal learning environment. Dashed lines represent the idea that learning should not be limited with the schools. Students, as this framework suggests, should be encouraged to seek knowledge in other environments as well. For example, students who are seeking solution for a problem may carry out their projects after school hours and get help from a role model. These projects can determine students' grades and later they can present their projects in a science fair in the school. Lastly, within the formal learning environment, other contextual factors are likely to play vital roles.

Other factors in the framework are rigorous curriculum and instructional strategies (see Figure 2; Lynch et al., 2013; Marshall, 2010; Subotnik et al., 2011). Setting standards high may not create any change unless a rigorous curriculum integrating STEM disciplines accompany them (Haycock, 2001). A rigorous curriculum should (a) prioritize standards, (b) name each unit, (c) assign standards to the units, (d) construct a calendar, (e) include effective teaching strategies, (f) integrate formative assessment, (g) create pre- and post-unit summative assessment, and (h) provide remediation intervention before each unit (Ainsworth, 2010). Instructional strategies, such as project-based learning, emerged with reforms and aligned with rigorous curriculum are also essential components of this framework. Teaching and learning in STEM disciplines may require such instructional strategies that provide immersion and continuity. In addition, integrating one or more STEM disciplines may not be actualized with traditional instructional strategies. Finally, the framework suggests rigorous curriculum and instructional strategies of change should meet in advanced coursework.

Another contextual factor in this framework is advanced coursework in which connections made among STEM disciplines (see Figure 2). Such coursework is necessary to prepare students for college (Lynch et al., 2013; Subotnik et al., 2011). In college, students may not complete their program when they are faced with challenging curriculum. Studies also show students who take advanced coursework are performing better on standard tests (Schmidt, 2011) and are more likely to obtain STEM degrees (Haycock, 2001; Schmidt, 2011; Tyson et al., 2007). Looking from the reverse perspective, students who take low level coursework perform lower on standard tests (Haycock, 2001; Schmidt, 2011). Lastly, as this framework suggests, integration of technology into advanced courses may increase efficiency of learning.

Technology resources are another contextual factor in the school ecology framework (see Figure 2). Researchers have indicated technology is highly important when teaching and learning occur based on inquiry (Lynch et al., 2013; Marshall, 2010; Subotnik et al., 2011). In a technology driven society, technologically driven practices need to be included in the classroom practice. With the help of technology, students can quickly access information and their mentors while conducting research. Unlike the days when technological devices were rare, teachers and students are likely to have easy access to computers and other tools today. Therefore, the lack of technology is not presently a problem. However, the problem is how teachers integrate technology into their practices (Richardson, 2012). For this aim, the framework suggests teachers should be well trained with technology use in their classrooms. Finally, they should receive constant instructional guidance from professionals. All the contextual factors mentioned above are meaningful when actors in the school ecology framework use them in collaboration.

## Collaborative Actions

Collaborative actions within an ecosystem are defined as relationships of actors (Weaver-Hightower, 2008). Collaborative actions of actors, in the school ecology framework, include teaching, learning, immersion, communication, partnering, mentoring, support, and assessment (see Figure 2). All actions in the framework emerge as a result of cooperation and symbiosis among actors rather than competition and predation as in the natural sciences (Weaver-Hightower, 2008).

Communication, one of the actions coming into prominence in the framework, can be established inside and outside the classroom (see Figure 2). Research shows two exemplifying characteristics of highly successful and highly diverse schools are open communication channels and shared responsibilities (Erdogan et al., 2013). Another research states students take advantage of learning opportunities when teachers explicitly indicate the rules and norms for classroom behavior and academic achievement (Lee, 2011). Finally, actors outside the school, in this framework, can also be in this communication loop.

Partnering is another prominent action in the school ecology framework (see Figure 2). Particularly, teachers and community leaders partner with role models (Lee, 2011; Marshall, 2010; Subotnik et al., 2010). Inquiry and research in cross-disciplinary STEM areas require more support not only from teachers but also from parents and other STEM professionals (Marshall, 2010). For example, teachers and community leaders within the framework can partner with university faculty members, technicians, business/industry leaders, other STEM professionals, and parents. Finally, role models in partnering organizations help students decide to pursue STEM majors and careers.

Mentoring can be counted as one of the collaborative actions in the school ecology framework (see Figure 2; Brody, 2006). Subotnik et al. (2010) indicated students have stereotypes that discourage them from pursuing a STEM degree. Therefore, mentoring can positively affect the scientist image in students' minds. Also, supporting students from underrepresented groups via mentoring may ensure they will pursue STEM majors and careers (Lynch et al., 2013). In addition, mentor-guided studies prepare students for college. Finally, another form of support, as this framework suggests, is assessment.

Both formative and summative assessments are essential collaborative actions in this framework (see Figure 2). Duschl, Schweingruber, and Shouse (2007) stated formative assessment is important to facilitate teaching and learning rather than to measure students' learning. Therefore, teachers can use their formative assessment skills by integrating them into their instructional practices.

Researchers indicated formative assessment addresses each student's needs and moves them toward meaningful learning goals (Duschl, Schweingruber, & Shouse, 2007; Minstrell et al., 2011). Therefore, using formative assessment as a support for students' development may help teachers to close the achievement gap in the classroom. For validation of students' learning, summative assessment can still be used. However, a variety of summative assessment, such as open-ended questions, multiple choice tests, essays, reports, portfolios, presentations, and oral examinations, may be necessary to allow for student improvement (Harlen & James, 1997).

## Implications of The School Ecology Metaphor

Weaver-Hightower (2008) used an ecology metaphor to describe school policy ecology. Stakeholders (i.e., education leaders, policymakers, and researchers) with an interest in STEM education can use this same metaphor to describe specialized STEM schools. This metaphor, used as a school ecology framework, provides benefits for stakeholders in STEM education who wish to (a) define strategies to solve problems from a broader perspective, (b) identify actors and actions in learning environments, (c) respond to key arguments from actors within the different learning environments, (d) reveal relationships among and between the actors, and (e) determine strategic flaws or opportunities in the system. Taken together, these benefits should help education leaders, policymakers, and researchers analyze the school ecology metaphor. Education leaders, policymakers, and researchers should not forget; specialized STEM schools are dynamic. As a result, these schools are likely to change. However, these stakeholders should also not forget; making a single change in one dimension of the school ecology can have large-scale effect. Therefore, education leaders, policymakers, and researchers should consider interventions at many levels within the school ecology (Weaver-Hightower, 2008).

## Conclusion

In this theoretical study, we focused on specialized STEM schools to answer six questions. These questions were related to the historical background of and learning environments found within these schools as well as the demographic characteristics and college and career readiness of students within these schools. We found these schools are unique and comprehensive environments. In addition, we found critical design components for these schools. Also, three common models are used to describe these schools. Students from all ethnic backgrounds are likely to benefit from attending these schools but may not necessarily pursue STEM education in college. Finally, students attending specialized STEM schools are more likely to actualize college goals when compared to peers from regular schools.

Scholars' theoretical ideas and empirical findings contributed to this theoretical study. Participatory research on these schools provides engagement and negotiation for researchers. We contend the school ecology metaphor can contribute to expanding definitions for these schools and understanding of who is involved in learning environments. However, caution must be used when making inferences for specific learning environments from broad generalizations about actors, contextual factors, and actions. Unintended consequences may result without regard for the specific environments.

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