A Pathway to Success? A Longitudinal Study Using Hierarchical Linear Modeling of Student and School Effects on Academic Achievement in a Middle School STEM Program

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Danielle R. Chine

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Dedication

This research study is dedicated to all the teachers in my life:

To Merrily, my mother and professor of education in hidden curriculum, who taught me everything not found in books. When stating, “Let me tell you something”... I took notes.

To Brian, my late father, you were always so proud. Even though you cannot be here, I want you to know it's okay.

To Bucka, my grandma and the smartest woman I know, may you accept this dedicated work as evidence of your own success having helped raise a “big geel”.

To Lana and Lucy, may your mother’s accomplishments inspire you to achieve even better in your own lives, always speaking up for those that have no voice. Be the ones.

To Melanie, my sister, may this work make you as proud of me as I am of you.

To David Thomas, your support and love propelled me forward. This is just the beginning…

To Mariel Sallee, educational leader, who encouraged my growth as an educator, when asked if I should pursue a doctorate he replied, “The question should be, why not?”

To Vince Colaluca, whose progressive decisions as a Superintendent, though not considered necessary at the time by many, prepared a district for the unforeseeable: a pandemic causing all schools to use district-wide blended learning. May this dedicated body of work prove as recognition never claimed, yet well-deserved.

Danielle R. Chine

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CHAPTER 1: THE CONTEXT OF ACADEMIC ACHIEVEMENT AND STEM EDUCATION

"The most important thing we can do is inspire young minds and to advance the kind of science, math, and technology education that will help youngsters take us to the next phase of space travel."

John Glenn (2000)

On July 20, 1969, three American astronauts, Neil Armstrong, Buzz Aldrin, and Mike Collins completed the first manned mission to the moon. Over 650 million people watched on television in eager anticipation, the most viewed event in history at the time, as Armstrong took the first human steps on Earth's only natural satellite (National Aeronautics and Space Administration [NASA], 2020). Fueled by the Space Race with the Soviet Union beginning in the mid-1950s, the United States was able to relinquish technological superiority with a few human steps (Space Race, 2010). This pivotal event sparked American interest in science, technology, engineering, and mathematics which has since been promoted many times after this "giant leap for mankind" in American history (NASA, 2020).

The Space Race, commencing in the 1950s, produced many science initiatives under President Dwight D. Eisenhower due to the increasing national belief that scientists in the Soviet Union were surpassing U.S. scientists in advancing technologies. Aside from NASA, the National Defense Education Act (NDEA) signed in 1958 demonstrated the federal government's continuing involvement in public education and gave funding to both public schools and college institutions. The two primary goals of the NDEA were to produce military and college graduates with advanced technological skills and provide financial support to college students through the National Defense Student Loan (NDSL) program (Schwegler, 1982). That same decade, the Defense Advanced Research Projects Agency (DARPA) was created with the sole mission still stated today: "To make pivotal investments in breakthrough technologies for national security" (DARPA Editors, 2020).

In 1983, *A Nation at Risk* was published as an educational reform policy reviving the importance of science, technology, engineering, and mathematics in public education. This landmark report in American educational history unveiled the common misconception among the public that Americans were leading the world in production, commerce, and education. The report shared some staggering statistics: 23 million American adults were functionally illiterate and the average achievement of high school students on standardized tests was lower than it was 26 years prior when Sputnik was launched (National Commission for Excellence in Education [NCEE], 1983). The latter was a particularly hard pill to swallow for Americans who remembered watching the Moon landing with national pride. *A Nation at Risk* reflected upon the dismal state of the American educational system. Shocked Americans were to learn that not only did they not lead the free world in education and advancing technologies, rather they lagged behind:

The time is long past when American's [*sic*] destiny was assured simply by an abundance of natural resources and inexhaustible human enthusiasm, and by our relative isolation from the malignant problems of older civilizations. The world is indeed one global village. We live among determined, well-educated, and strongly motivated competitors. We compete with them for international standing and markets, not only with products but also with the ideas of our laboratories and neighborhood workshops. America's position in the world may once have been reasonably secure... it is no longer. (NCEE, 1983)

The risk is not only that the Japanese make automobiles more efficiently than Americans and have government subsidies for development and export. It is not just that the South Koreans recently built the world's most efficient steel mill, or that American machine tools, once the pride of the world, are being displaced by German products. It is also that these developments signify a redistribution of trained capability throughout the globe. Knowledge, learning, information, and skilled intelligence are the new raw materials of international commerce and are today spreading throughout the world as vigorously as miracle drugs, synthetic fertilizers, and blue jeans did earlier. If only to keep and improve on the slim competitive edge we still retain in world markets, we must dedicate ourselves to the reform of our educational system for the benefit of all - old and young alike, affluent, and poor, majority and minority. Learning is the indispensable investment required for success in the ‘information age’ we are entering (NCEE, 1983, p. 10).

The echoes of these words from almost 40 years ago were particularly poignant as the nation faced economic turmoil, flailing infrastructure, and a need for advanced medical technologies in the wake of the Covid-19 pandemic that struck the nation in early 2020. The need for science, technology, education, and mathematics in education is becoming more and more important as the nation works in collaboration with business, medicine, and commerce to develop cures and vaccines to eradicate a virus plaguing modern society. Our nation is at risk now, just as it was in 1983.

The 1980s was a monumental time in calling to light the development of STEM education particularly through the American Association for the Advancement of Science (AAAS). The AAAS was founded in 1848 with the goal of increasing collaboration and exchanging of information among scientists to advance scientific progress at an increasing pace. Currently, it is the largest scientific organization in the world with over 120,000 members comprising experts in astronomy, education, engineering, medical sciences, etc. In 1985, sparked by the passing of Haley's Comet, the AAAS created Project 2061. This long-term scientific initiative aimed at improving American technological, mathematic, and scientific literacy. Project 2061 developed a comprehensive set of K-12 learning goals with state and national science standards creating the *Next Generation Science Standards.* In addition, the AAAS formed the *Atlas of Science Literacy, Benchmarks for Science Literacy, and Science for All Americans.* The latest defines science literacy and specifically explains standards and curriculum topics, best practices in learning and teaching, and basics of educational reform (AAAS Editors, 2020).

In 2012, recognizing the need for further STEM education policy, President Barack Obama created the *Educate to Innovate* campaign promising to prepare the nation's youth in the areas of STEM education, computer science, and technological literacy. During President Obama's first term, he emphasized the importance of math and science preparation through funding under the Elementary and Secondary Education Act (ESEA), Race to the Top (Rttt), and the Investing in Innovation Fund (i3). During Obama's second term, he shocked the nation by proclaiming during his 2013 state of the union address the coming of a "Sputnik moment" with the facilitation of government investment in infrastructure, education, and research (Obama, 2013). In addition, three billion dollars was given to 14 federal agencies such as the U.S. Department of Education, National Science Foundation (NSF), and the Department of Energy to invest in STEM education programs to provide STEM education and computer science programming (Handelson & Smith, 2016). President Obama emphasized, during his *STEM for All* speech at the National Science Fair in 2013, the importance of an "all-hands-on-deck approach to science, technology, engineering, and math… We need... to make sure that all of us as a country are lifting up these subjects for the respect they deserve" (Obama, 2013).

Shortly after the *Education to Innovate* campaign, President Obama signed the STEM Education Act of 2015 expanding training and research programs to teachers in math and science. This occurred via the National Science Foundation (NSF) scholarship program, improving informal STEM education research, and formally adding computer science into the definition of STEM education (STEM Education Act, 2015).

That same year, and several decades after *A Nation at Risk* was released, the Every Student Succeeds Act (ESSA) was signed in 2015. This educational reform and policy replaced the No Child Left Behind (NCLB) legislation from 2001 and transferred more power to local entities and states (Achieve, 2017). The passage of ESSA has given local school districts the decision-making power and funding to provide formal STEM programming, digital literacy curriculum, and the purchasing of technology (ESSA, 2017).

In 2019, two bills were passed through Congress further enhancing public education's ability to provide STEM programming to meet the needs of all students including underrepresented populations. The *STEM Research and Education Effectiveness and Transparency Act* was passed allowing for broadening participation in NSF research and educational programs including STEM education (STEM Research and Education Effectiveness and Transparency Act, 2019). The second bill, the *21st Century STEM for Girls and Underrepresented Minorities Act* provided grants to local educational agencies to empower girls and other underrepresented minorities to participate in STEM programs and pursue STEM field careers (21st Century STEM for Girls and Underrepresented Minorities Act, 2019).

Throughout the history of STEM education and initiatives, there have been gaps in both student participation and academic achievement among underrepresented populations, such as students who are economically disadvantaged, minorities, and female students (Beede et al., 2011; Gonzalez & Kuenzi, 2012; Hebebci, 2019; Kennedy & Odell, 2014; Sanders, 2009; National Science Board, 2019). According to Gonzalez and Kuenzi (2012), many other researchers and economic experts agree that underrepresented groups are an untapped resource for potentially filling many STEM-related positions currently needed in the workforce. They explained that the exposure to STEM and increase in participation in STEM fields among women and racial minorities may pose a solution to the labor shortage described by Kennedy and Odell (2014) and Gonzalez et al. (2012). One of the main purposes for the formation of the NDEA is to recruit and support underrepresented populations by cultivating American talent to join STEM fields. Under NDEA, the federal government developed national programs to urge and support women and minorities to pursue careers and higher education in scientific and engineering fields (Association of American Universities, 2006).

All of these government regulated policies discussed such as the NDEA, and later, *The STEM Research and Education Effectiveness and Transparency Act* and the *21st Century STEM for Girls and Underrepresented Minorities Act* have provided funding for STEM programming and curriculums in one way or another. In fact, in 2019, the Department of Education under President Trump announced an investment of $540 million to support STEM education via research and educational grants. The importance of providing grants for STEM education is to propel the mission of the Department of Education. Secretary of Education, Betsy Devos stated, “[The mission is] to promote student achievement and preparation for global competitiveness by fostering educational excellence and ensuring equal access” (U.S. Department of Education, 2018, p. 9096).

There has been overall minimal research and evaluation on the effectiveness of STEM education programs. The last major evaluative report occurred in 2007 with a review by the Academic Competitiveness Council ([ACC], 2007) on the effectiveness of federally-funded STEM programs. The ACC evaluated 115 STEM programs to assess their effectiveness on student achievement and performance. The ACC determined that despite substantial investment, there was little evidence of academic benefit, educational gain, or increase in students’ performance as a function of these programs (ACC, 2007).

As the substantial amount of funding for these programs continues to increase, there is a significant need to regulate and monitor STEM education and programming. Private sector companies are also cashing in on this available revenue source. These companies individually develop their own STEM curriculum and programming. Currently, the most popular STEM and engineering curriculum companies in the United States are Project Lead the Way

(PLTW), Engineering by Design (EbD), EverFi, and STEM Education Works. PLTW is presently the curriculum most used nationally (VentureRadar, 2020). Several states are providing funding for PLTW programming in their public schools such as Wisconsin, Illinois, and Iowa (Schmid, 2007). The direct transfer of taxpayer's dollars into the pockets of private curriculum companies has become a recent issue in STEM education and raises the question: How effective is STEM programming on student achievement? Many educational leaders and stakeholders wonder if these costly STEM curriculum programs are providing a 21st-century education and teaching students the necessary skills to be successful both on state assessments and in the workforce.

Statement of the Problem

Throughout the past two decades, there has been an increase in STEM education initiatives in kindergarten through 12th grade and beyond. In addition, funding to public schools to provide integrated STEM education from federal and other private sources has increased. There is also overall increased need for STEM education programs and instruction. Despite these facts, little research has been conducted on the impact of these programs on student achievement, particularly in the middle school grades. The effect of STEM programs on student success both in school and in the future workforce is an under-researched area in education. Additionally, there is ambiguity in defining integrated STEM education among educators and researchers. The backbone of STEM education is found in the foundations of project-based learning (PBL) and the constructivists education theories of Dewey and Piaget. These basic theories assist with defining and explaining the theoretical framework of STEM education as it exists today. The broad definitions and effect of STEM programming and PBL on student achievement is a necessary topic of research to determine the effectiveness of these increasingly popular and often expensive instructional programs.

Theoretical Framework

STEM Education

There are a few fundamental theories supporting STEM education which are pertinent to the theoretical framework of this research study. The central theory grounding this research is project-based learning PBL theory. Constructivism is another foundational theory supporting the work in this study. Other secondary theories framing this study are teacher collective efficacy and student self-efficacy. Both of these concepts account for the teachers' and individual student roles and responsibilities for their own learning.

Project-Based Learning (PBL)

The majority of STEM curriculum and programs use PBL theory as the main approach to providing STEM instruction. The use of the PBL approach as a method of utilizing student-specific pedagogy was first introduced in medical school by Barrows and Tamblyn at McMaster University in the 1960s (Hildebrand, 2018). Barrows and Tamblyn felt the traditional method of providing medical school education required students to memorize and acquire a substantial amount of information that was taught in isolation with no relevance or application. This was particularly the case in the first two years of medical school when students traditionally did not see patients or have any connections to clinical-based medicine. Barrows and Tamblyn developed a PBL curriculum within the four years of the medical school program that fostered relevance and application using real-world application and interdisciplinary methods (Hildebrand, 2018). Today PBL is used not only in medical schools but kindergarten through the 12th grade and in other areas such as business, engineering, law, and social sciences (Haggbloom et al., 2002).

The PBL environment proposed by Tamblyn and Barrows in the 1960s is very similar to the method of implementation today, which consists of five characteristics. These, as described by Marra et al. (2014), are defined as being problem-focused, student-centered, self-directed, self-reflective, and facilitative. All of these fundamental characteristics find their roots in the foundations of constructivism theory (Marra et al.).

Constructivism in Education

Constructivism is an educational learning theory which relies upon the learner's understanding and prior knowledge of experiences to increase new learning. It is often referenced in the philosophies within ontology, ethics, politics, and particularly epistemology (Matthews, 1998). In constructivism learning theory, all learning is built upon prior learning, or "constructed" from prior knowledge (Nola & Irzik, 2006). The roots of constructivism are grounded in educational psychology by Jean Piaget and his development of the theory of cognitive development. Piaget's learning theory concentrated on human development and how humans connected their past experiences and ideas transforming this acquired knowledge into new learning (Piaget, 1971). Other educational theorists have expanded on Piaget's work adding their own specialization. Lev Vygotsky's theory of social constructivism described how interactions with adults, other peers, and educational tools are used to form new mental constructs within a student's zone of proximal development (Constructivism, 2020). Jerome Brunner stretched Vygotsky's social constructivism theory even further by introducing the idea of instructional scaffolding, or the providing of supports which are slowly withdrawn as the learner gains more understanding and ability (Seiffert & Sutton, 2009). Several other philosophers and writers have contributed to Piaget's constructivist learning theory, such as Maria Montessori, Wladyslaw Strzeminski, Heinz von Foerster, George Kelly, Herbert Simon, Paul Watzlawick, Ernst von Glasersfeld, Edgar Morin, and Humberto Maturana (Constructivism, 2020). These scholars, along with many others, paved the way for PBL methodologies and the educational pedagogy used in STEM education today.

Most STEM education curriculums and programs like PLTW, EverFi, and PBL programs like the All American Soap use the five aspects of the learning cycle developed by Bybee (1997) as a foundational learning model derived from constructivist theory. The five aspects of the learning cycle theory are: engagement, exploration, explanation, elaboration, and evaluation. Engagement involves posing the problem to students, ensuring they make connections to previous learning, and pre-assessing existing knowledge. During the exploration phase, students actively collect data. Explanation occurs when students apply their collected data to the research problem, make connections with their learning, and bring in new knowledge and vocabulary words. The fourth phase, elaboration, involves students presenting and actively applying their new learning to the research problem. This occurs in conjunction as the teachers present new challenges which require critical thinking to solve. Lastly, the evaluation phase assesses student's learning, not necessarily in a pencil-paper test, but through presentation of the research problem and solution and final outcomes of the project (Bybee, 1997). This five-step learning cycle uses Piaget's theory of cognitive development and requires students to apply prior knowledge and construct new knowledge from their learning experiences (Seifert & Sutton, 2009).

Constructivism is often referenced when discussing pedagogic concepts that encourage active learning, or what educational theorist and American philosopher John Dewey identified as, "learning by doing" (Savery, 2006, p. 16). Dewey believed that new learning occurs by acquiring new experiences and incorporating it into prior knowledge. His hands-on approach to learning paved the way for the foundations of PBL and other progressive educational practices used today (Savery, 2006). In *My Pedagogic Creed,* Dewey stated, "I believe that the school must represent present life – life as real and vital to the child as that which he carries on in the home, in the neighborhood, or on the playground" (1897, p. 77). Educational theories using common sense and straightforward application of acquired knowledge in the learning of new skills, such as Dewey's, is pertinent to the theoretical framework of this research study.

Dewey on Education and Teachers

The foundational theories of education established by Dewey are most prominent in the following works: *My Pedagogic Creed* (1897), *The School and Society* (1900), *The Child and the Curriculum* (1902), *Democracy and Education* (1916), and *Experience and Education* (1938). The latter and his most prominent writings pertain to the theory and application of PBL and STEM education (Savery, 2006). Dewey emphasized that learning is a social and interactive process with school reform necessary to allow for the gaining of experience and interaction with curriculum. He believed that students should take ownership of their learning and all students should have an opportunity to learn through experience, particularly through "hands-on" learning (Dewey, 1897, p. 78).

Although Dewey was a prominent believer that students should take responsibility in their learning, he also believed the role of the teacher is equally important. Dewey concluded that a teacher's love and passion for learning is more influential to student's learning than content knowledge. According to Dewey, "the best indicator of teacher quality is the ability to watch and respond to movement of the mind with keen awareness… as students respond to subject-matter presented" (Dewey, 1904, p. 15). Teachers are important when it comes to student success in gaining knowledge from a constructivist perspective and in the theoretical framework of this research study.

Teacher Effectiveness in STEM Education

There is a plethora of research on the belief of Dewey and other constructivists on the impact of teacher effectiveness in students' learning (Savery, 2006). In addition, there is a wide variety of opinions among researchers and educators regarding the effectiveness of teachers in instructing STEM education and PBL programs. STEM education is often difficult for teachers to implement due to the interdisciplinary nature requiring teachers to combine several subjects. The current educational system was designed to teach the core subjects of science, technology, engineering, and math in isolation. Teachers were not taught to instruct all subjects in conjunction (Lesseig et al., 2017). In addition, Lesseig et al. commented that teachers tend to feel overwhelmed and unsure while teaching STEM as often standards being taught span grade levels and merge into different subjects that are often not within a teacher's training field. The concerted teaching of all subjects is called integration. According to Wang et al. (2011) and many other researchers, integration is most successful when teachers believe students are learning effectively and growing in science and mathematics.

There are many components of teaching that impact teacher effectiveness in teaching STEM education. One of the major indicators of teacher effectiveness is how comfortable and prepared teachers are in teaching STEM courses (Stohlmann et al., 2012). Gonzalez and Kuenzi (2012) reported in a study spanning over 20 years that teachers who earned a college degree in mathematics or science had a substantial positive impact on student achievement. They stated that in the U.S., most high school teachers do not have a college degree in the subject they teach but possess only a degree in secondary education. Most commonly, mathematics teachers are the least likely to hold a college degree in mathematics (Gonzalez & Kuenzi, 2012).

Conversely, some researchers disagree and believe that higher teacher content knowledge does not directly correlate with greater student achievement and teacher effectiveness. They state that teachers who hold a subject-specific degree and demonstrate expertise in that area are not necessarily effective teachers. Previous studies cite weak or no correlation linking student success and teacher content knowledge (Atkinson, 2012). "It is unrealistic to expect teachers to teach or promote engineering when most K-12 teachers do not have a good understanding of engineering practices, applications, or careers" (Pinnell et al., 2013, p. 28). In addition, most undergraduate teacher education programs do not provide engineering principles or practices to prepare teachers for instructing STEM education (Pinnell et al.). Currently, there is a lack of effective preservice STEM education for educators which has created a shortage of quality STEM educators at the elementary and middle school level (Radloff & Guzey, 2016).

Collective Teacher Efficacy

The most important and powerful factor influencing student achievement is the educator's own belief that students can learn and overcome challenges. This phenomenon is called teacher collective efficacy, a concept coined by John Hattie in his meta-analysis reviewing over 800 studies of factors influencing student achievement (Hattie, 2009). Collective teacher efficacy refers to the "collective self-perception that teachers in a given school make an educational difference to their students over and above the educational impact of their homes and communities" (Tschannen-Moran & Barr, 2004, p. 190). The belief of teachers that together they can make a difference outranks all other factors impacting student achievement, such as socioeconomic status, home environment, and previous achievement. The influence of teacher collective efficacy on student achievement has a reported effect size of 1.57, more than double the effect size of other reported impactful factors such as feedback (Hattie, 2009).

The importance of teacher collective efficacy and its impact on student achievement is pronounced in the STEM arena, as well as the general education setting. In addition, individual teachers and their personal beliefs and perceptions that they can grow and impact student achievement is crucial to student success. Stohlmann et al. (2012) discussed the importance of teachers' self-efficacy and the belief that they can achieve their goals of effectively educating students. A critical component of the development of teacher self-efficacy is solid content knowledge and understanding of pedagogy (Er, Artut, & Bal, 2022; Kartal & Dilek, 2021; Simsar & Jones, 2021; Stohlmann et al., 2012). Increased student motivation, self-esteem, and the development of student self-efficacy is reported when teachers feel they themselves are successful as educators. The development of self-efficacy is an obstacle among STEM educators as they need more expansive content knowledge and advanced pedagogy to provide quality interdisciplinary STEM education (Stohlmann et al., 2012). The understanding of STEM pedagogy is difficult and can be time consuming, particularly for beginning educators (Macalalag et al., 2022; O'Neill et al., 2012). Many preservice STEM educators feel ill-prepared to instruct students in the discipline (Radloff & Guzey, 2016).

Boyd et al. (2009) researched the connection between teacher preparation and student achievement and determined, regardless of educational field, the direct link between preparation and practice in the first year of teaching is the most successful. Teachers who are prepared and determined in their first year in education have the most impact on student achievement. In addition, teacher preparation programs focusing on the work of the classroom and teachers who actively instruct in the field are impactful for student achievement (Boyd et al., 2009).

There are four sources of creating and shaping collective teacher efficacy beliefs: mastery experiences, social persuasion, affective states, and vicarious experiences. The former source, mastery experiences is reported to be the most powerful (Bandura, 1977; Bandura, 1986). When teachers experience success, such as student achievement attained, they attribute it to factors within their control. This increases their collective efficacy which fuels further mastery experiences and continues a streak of student achievement (Donohoo, 2009). This positive feedback loop creates a snowball effect continuing both increasing the frequency of mastery experiences and furthering student achievement.

Purpose of the Study

The purpose of this study is to define integrated STEM education within the context of middle school and determine the impact STEM programming has on student academic achievement compared to their grade level peers participating in a general education setting. This study determined the impact of an integrated STEM education program on student achievement at the middle school level accounting for other factors affecting student performance such as gender, race, socioeconomic status, and attendance rate. The effect of integrated STEM programming on student achievement determined the interaction effects of demographic factors and student’s attendance rates.

Research Question

The research question addressed in this study is to determine the impact of middle school integrated STEM programming on student achievement. Currently, little research has been conducted on the impact of STEM programming and instruction on student academic performance, particularly achievement. The primary question to be addressed in this research is as follows:

- Does middle school integrated STEM programming positively affect student achievement?

The impact of the following potential moderators on student achievement determined: gender, race, socioeconomic status, and attendance rate.

Objectives of the Study

The main objectives of this study are as follows:

1. Define and explain middle school STEM integrated programming.
2. Determine the interaction effects of factors impacting student achievement of middle school students participating in STEM integrated programming. To determine the interaction effects of factors impacting student achievement on Ohio state assessments in English language arts (ELA), math, and science by use of projected proficiency calculations for students participating in integrated STEM programming compared to the projected proficiency of general education students. The following factors investigated to determine possible interaction effects: gender, race, socioeconomic status, and student attendance rate.
3. Determine the effect of middle school STEM integrated programming on student achievement. To test student achievement using Ohio state assessments in English language arts (ELA), math, and science for those who participated in middle school STEM programming compared to general education students.

Research Questions

The research question addressed in this study is to determine the impact of middle school integrated STEM programming on student performance and achievement. Currently, little research has been conducted on the impact of STEM programming and instruction on student academic performance, particularly performance and achievement. The primary research question to be addressed in this research is as follows:

Does middle school integrated STEM programming positively affect student achievement? Additional research questions related to the primary questions include:

Research Question 1

Do students participating in an integrated middle school STEM program demonstrate differences in academic achievement in ELA, math, and science compared to students participating in a traditional general education setting?

Research Question 2

Do students participating in the integrated middle school STEM program demonstrate differences in achievement due to the interaction effect of gender, race, socioeconomic status, or attendance between the STEM program students and general education students?

Methodology

This quantitative research study may help to determine the impact of integrated STEM education on student academic achievement. This was a longitudinal case study analyzing student performance on OST over the course of seven years commencing in the 2012-2013 school year and ending the 2018-2019 school year. First, the definitions of integrated STEM education and PBL were described chronicling the PLTW curriculum utilized and other STEM-related projects encompassing the middle school STEM program researched in this study. Second, student performance was measured using achievement data on OST in math, English language arts, and science tests over the course of seven years. Students' OST data were analyzed using hierarchical linear modeling (HLM), a type of multilinear modeling used to determine the variance among variables in nested data, or data at different hierarchical levels. Through the use of HLM, interaction effects of the following demographic factors were analyzed to determine their impact on student achievement: student race, socioeconomic status, gender, and attendance rate.

Significance of Study

The results of this study are highly influential and beneficial to educational administrators and policymakers to gain insight into the academic gains of providing STEM programming.

This research would provide educational leaders with a clearer view of the impact and effectiveness of STEM programming on student achievement. This could assist them with making future educational and fiscal decisions regarding the planning, purchasing, and implementing of STEM programs, particularly at the middle school level. In addition, this research would benefit students as it will help determine the benefits of STEM education programs on future student success both on state assessments and on providing mastery experiences.

Role of the Researcher

The researcher in this study has a solid foundation in math, science, and similar STEM subjects and holds a Bachelor of Science degree in Chemistry and a Master of Science degree in Inorganic Chemistry. The researcher also earned a Master of Arts degree in Educational Administration and Leadership with principal licenses for middle and high school with a degree focused on establishing and implementing change. The researcher began her career teaching middle school math, science, and STEM courses for three years at the school of interest in the study before becoming the kindergarten through 12th-grade STEM instructional coach for the school district. The researcher was the district STEM instructional coach for several years creating, strengthening, and expanding 21st-century initiatives and programs from kindergarten to the 12th grade. For the past two years, this researcher has been the Supervisor of School Improvement and Curriculum in a medium-sized, urban school district in a neighboring county to the school of interest in the study.

Limitations

There are a few limitations to this research study. First, the study population is limited to a single institution versus data collection from other similar programs in the state. The limitation of only including data from one institution prevents generalizability of the researcher's conclusions. Second, student demographic information was self-reported by families and parents for several factors such as student race, gender, and socioeconomic status. This can limit the validity of the research study. The transition from PARCC to AIR assessments for mathematics and English language arts can create reliability issues as two different assessments were used to measure student achievement. Other factors seemingly unrelated to the STEM program may have effects on student achievement. It is hypothesized that teacher experience and self-efficacy plays an important factor in student learning and achievement. The STEM programs studied consisted of very few teachers providing STEM-integrated instruction. This makes it difficult to determine the effects of student achievement as a function of teacher effectiveness in general or due to the STEM programming and curriculum itself. In addition, there were only two integrated STEM teachers for each academic year. This can make it difficult to determine if students' academic achievement was related to STEM programming or to the curriculum and instructional materials provided. This is connected to the influence of collective teacher efficacy and its impact on student achievement. Finally, migration of students in and out of the STEM program may be a threat that affects both internal validity and reliability. Fortunately, the migration or number of students exiting the STEM Program is limited with very few students exiting the program before the end of each academic school year.

Delimitations

The delimitations in this research study include the number of participants. The results encompassed middle school students attending an urban, traditional school with approximately 350 students per grade level and 25 students participating in integrated STEM programming within each grade level, respectively.

Definition of Terms

Achievement gap- the disparity in academic performance between groups of students, particularly in test scores. The achievement gap shows up in grades, standardized-test scores, course selection, dropout rates, and college-completion rates, among other success measures is most often used to describe the troubling performance gaps between African-American and Hispanic students, at the lower end of the performance scale, and their non-Hispanic White peers, and the similar academic disparity between students from low-income families and those who are more affluent (Ansel, 2011).

Achievement growth- refers to academic progress made over a period of time measured from the beginning to the end of the defined period. The tracking of achievement growth can be tracked and determined for individual students, schools, states, or countries, and a wide variety of variables and methodologies may be used to determine whether "growth" is being achieved (Achievement Growth, n. d.).

"All STEM for Some"- A framework of providing STEM education where students in elementary, middle, and high school who show the most interest in STEM disciplines are fully immersed in STEM education (Atkinson, 2012, Section 1).

Engineering- is a body of knowledge about the design and creation of products and a process for solving problems. Engineering utilizes concepts in science and mathematics and technological tools (Honey et al., 2014, p. 14).

Integrated STEM programming- a meta-discipline encompassing science, technology, engineering, and mathematics taught as an integrated whole (Morrison, 2006).

Mathematics- is the study of patterns and relationships among quantities, numbers, and shapes. Mathematics includes theoretical mathematics and applied mathematics (Honey et al., p. 14).

Science- is the study of the natural world, including the laws of nature associated with physics, chemistry, and biology, and the treatment or application of facts, principles, concepts, or conventions associated with these disciplines (Honey et al., p. 14).

"Some STEM For All"- A framework for providing STEM education where all students in elementary, middle, and high school are introduced to the basic fundamentals of STEM education (Atkinson, 2012, Section 1).

STEM- the study of science, technology, engineering, and mathematics taught as a whole with the primary goal of creating critical thinkers for the future workforce (White, 2014).

Technology- "is the study of the entire system of people and organizations, knowledge, process, and devices that go into creating and operating technological artifacts, as well as artifacts themselves" (Honey et al., p. 14).

Organization of the Study

This study is organized in the following format:

- Chapter 1 introduces the research problem and provides rationale for the study. The introduction, statement of the problem, conceptual framework, basis of STEM education, and the purpose of the study are provided. Also included are the definitions, assumptions, delimitations, and limitations of the study.
- Chapter 2 contains the review of the literature in reference to the study. This literature review provides the definition, history, and an overview of current STEM education. Also included are curriculum and standards, an overview of integrated STEM education models, impact on student achievement, teacher effectiveness, teacher and student self-efficacy, and a review of post-secondary education and career readiness in relation to STEM education.
- Chapter 3 describes the research methodology, research model, the subjects, and the procedures for the analysis of the data related to student achievement.
- Chapter 4 presents the analysis utilized in the study. These analyses included the use of descriptive statistics and hierarchical linear modeling techniques to determine differences in achievement in the multilevel data of students, within a classroom, within a grade level, within a school.
- Chapter 5 concludes the study with a results' and discussion section determined from the analyses. Recommendations for further research based upon the conclusions are also presented.

Chapter Summary

This research examined the effect of STEM education and integrated STEM programming on student achievement in middle school grades six through eight. The need for this research is indicated due to the increase in educational policy and funding to public schools to provide STEM programming. There is limited regulation and monitoring of the academic success of these programs. The effect of STEM programs on student success both in school and in the future workforce is an under-researched area in education. Additionally, there is ambiguity in defining integrated STEM education among educators and researchers. The broad definitions and effect of STEM programming and PBL on student achievement is a necessary topic of research to determine the effectiveness of these increasingly popular and often expensive instructional programs. This quantitative, seven-year longitudinal study determined the effectiveness of STEM programming on student achievement, accounting for interaction effects of demographic factors, such as student race, gender, socioeconomic status, and student attendance.

Citation

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CHAPTER 2: THE LITERATURE REVIEW ON STEM EDUCATION

"It is important that we approach STEM [education] not as a subject, but as a mindset."

Camsie McAdams (date unknown)

For the past two decades, the realization of the importance of STEM education in the United States is increasingly gaining momentum from kindergarten into high school and beyond (Gonzalez & Kuenzi, 2012; Hansen & Gonzalez, 2014; Stieff & Uttal, 2015; White, 2014). Dugger (2010) and Hansen and Gonzalez (2014) reported that STEM education brings an interdisciplinary approach to traditional schooling, offering students opportunities to view an integrated world rather than learning subjects in isolation. The importance of STEM education as a method of teaching subjects together to foster innovation was mentioned by Barakos et al. (2012) stating, "The quality of modern life depends on innovation and development in the STEM disciplines" (p. 1). Researchers and educators have very diverse opinions regarding the current success of STEM education today (Gonzalez & Kuenzi, 2012; Bybee, 2013). Dugger (2010) stated some view STEM education as an opportunity for students to gain important skills necessary to succeed in today's global economy, while others view this method of teaching as interlaced with problems. There are many different views regarding best practice methods of providing STEM education and the role of STEM in educating students for the future workforce.

This literature review focuses on the definition of STEM education and provides an overview of the varying STEM integration models that are utilized by schools. In addition, methods of providing PBL, the history of STEM education, and the different curricula such as PLTW will be discussed. Current policy paving STEM education, impact on student achievement, curriculum and standards, and the contribution of STEM education to students' future success will be discussed.

Defining STEM Education

The National Science Foundation (NSF) was the first to name STEM education as Science, Mathematics, Engineering, and Technology (SMET) with the primary goal of creating critical thinkers for the future workforce (White, 2014). According to Sanders (2009), the program officer of the NSF commented in the 1990s "SMET" sounded too similar to "smut", which led to the creation of the "STEM" acronym (p. 20). Throughout the past two decades, the NSF has funded or assisted with the funding of several projects, such as the Technology for All Americans Project (TfAAP) (1994-2005) under the International Technology Education Association (ITEA). This created the *Standards for Technological Literacy: Content for the Study of Technology (STL)* and *Advancing Excellence in Technological Literacy: Student Assessment, Professional Development, and Program Standards (AETL)* (Dugger, 2010). Both of these projects are influential in the creation of the educational standards and foundations existing in STEM education.

Today the acronym STEM stands for science, technology, engineering, and math with the definitions of each subject defined as follows:

> Science- is the study of the natural world, including the laws of nature associated with physics, chemistry, and biology and the treatment or application of facts, principles, concepts, or conventions associated with these disciplines.
>
> Technology- is the study of the entire system of people and organizations, knowledge, process, and devices that go into creating and operating technological artifacts, as well as artifacts themselves.
>
> Engineering- is a body of knowledge about the design and creation of products and a process for solving problems. Engineering utilizes concepts in science and mathematics and technological tools.
>
> Mathematics- is the study of patterns and relationships among quantities, numbers, and shapes. Mathematics includes theoretical mathematics and applied mathematics. (Honey et al., 2014, p. 14)

The individual subjects of science, technology, engineering, and mathematics have learning standards by grade level according to the Ohio Department of Education (ODE). For science, *Ohio's Revised Science Education Standards and Model Curriculum* states, "By the end of high school, students should graduate with sufficient proficiency in science to: know, use, and interpret scientific explanations of the natural world, generate and evaluate scientific evidence and explanations, distinguishing science from pseudoscience, understand the nature and development of scientific knowledge, participate productively in scientific practices and discourse" (ODE, 2018, p. 3).

Ohio's Learning Standards for Technology (ODE, 2017) encompass all technological knowledge and skills students in kindergarten through12th grade need to know to succeed in a global economy and increasing technological society. The technology standards are separated by grade bands: kindergarten through second grade, third through fifth grade, sixth through eighth grade, and ninth through twelfth grade, respectively. They are categorized into three main disciplines: *Information and Communication Technology, Society and Technology, and Design and Technology* (ODE, 2017).

Ohio's Learning Standards for Math (ODE, 2019) describe many areas of expertise that educators should strive to accomplish with students. The following are some of the *Standards for Mathematical Practice:*

> make sense of problems and persevere in solving them, reason abstractly and quantitatively, construct viable arguments and critique the reasoning of others, model with mathematics, use appropriate tools strategically, attend to precision, look for and make use of structure, and look for and express regularity in repeated reasoning. (ODE, 2019, pp. 5-6)

There are no engineering standards in Ohio for kindergarten through eighth grade, however, as part of the *Ohio Career Field Initiative*, students as young as elementary school can begin career planning (ODE, 2019). For students in grades nine through twelve grade there are *Career Field Technology Content Standards* referenced within *Engineering and Science Technologies and Manufacturing Technologies* (ODE, 2019). These engineering standards are organized into seven strands:

- Business Operations/ 21st-century Skills,
- Electrical/ Electronics,

- Computer Integrated Manufacturing,
- Materials Joining,
- Pre-Engineering,
- Design and Development,
- Precision and Advanced Machining, and
- Industrial Maintenance and Safety (ODE, 2019)

There is a vast amount of ambiguity in defining both engineering and technology and in determining the appropriate grade-level standards beneficial to student future achievement and career success.

Integrated STEM Education

The importance of innovation and development of STEM disciplines is associated with a higher quality of life, and for this reason, is a recent topic of national conversation (Abdul Rahman, Zakaria, & Din, 2021; Barakos et al., 2012; Benek & Akcay, 2019; Chine & Larwin, 2022; Hebebci, 2021; Lindsay 2020; Marco-Bujosa, 2021; Preuss et al., 2020; Saricam & Yildirim, 2021; Talan, 2021; Williams & Young, 2021)). Stohlmann et al. (2011) proclaimed, "Our ever-changing, increasingly global society faces many problems that are multidisciplinary, and solving them requires the integration and application of multiple science, technology, engineering, and mathematics (STEM) concepts and skills" (p. 32). The need for problem-solving and critical thinking skills incorporating the subjects of science, technology, engineering, and mathematics is imperative to our nation's economic success and has created a collective conversation for the universal definitions describing STEM education (Ashford et al., 2016; Asigigan& Samur, 2021; Baharuddin et al., 2021; Batdi, Talan, & Semerci, 2019; Bradley 2021; Çetin 2021; Doganca Kucuk et al., 2021; Kim, Park, & Tjoe, 2021; Minken et al., 2021; Punzalan, 2022; Razi & Zhou, 2022; Seage & Türegün2020; Wannapiroon et al., 2021; Yang & Baldwin, 2020).

The definitions of STEM education for each subject of science, technology, engineering, and math clearly demonstrate the ambiguity in what defines STEM discipline. Due to the lack of clarity in the definition of STEM education, the term *integrated STEM education* was designed to encompass the discipline as a whole (Giasi, 2018). Honey et al. (2014) defined the emergent discipline of STEM integration as interdisciplinary, cross-disciplinary, connected, fused, or transdisciplinary with no definitive boundaries separating each discipline. Morrison (2006) referred to integrated STEM education as a “meta-discipline” or, stated by Kaufman et al. (2003), a “creation of a discipline based on the integration of other disciplinary knowledge into a new ‘whole’” (p. 6). According to Stohlmann et al. (2011), integrated curriculum, particularly at the middle school level, “provides opportunities for more relevant, less fragmented, and more stimulating experiences for learners” (p. 34) further stating “integrated mathematics and science has a positive impact on students’ attitudes and interest in school, their motivation to learn, and their academic achievement” (p. 34).

Although there is some ambiguity defining integrated STEM education, there is a clearer definition of what it is not, and common misconceptions. According to Morrison (2006) there are several false beliefs held by educators and research regarding STEM education methods. The first misconception is the belief that technology and engineering are layered into the core subject coursework of math and science. Instead of enriching both core subjects, teachers are adding and supplementing technology and engineering lessons. The second misconception is that technology only refers to adding the use of computers. Morrison (2006) clarified that the use of computers does not automatically constitute the use of technology and is not necessarily STEM-related. Additionally, technology does not always reference word-processing. According to Morrison (2006), another common misconception is that the term “hands-on” means active learning is taking place. Hands-on activities do not necessarily mean active learning is occurring. Other fallacies pertaining to STEM education listed by Morrison (2006) are: the idea that STEM omits laboratory study and the use of the scientific method, STEM-educated students must participate in technical fields and do not have the knowledge to pursue liberal arts education, math and science education are apart from each other, and the common misconception that engineering and technological education is difficult and troublesome for students (Morrison, 2006, p. 6).McClure (2017) discussed an additional common misconception regarding STEM education:

> The belief that ‘real’ science, technology, engineering, and mathematics learning doesn’t occur until children are older, and that exposure to STEM concepts in early childhood is only about laying a foundation for the serious STEM learning that takes place later. (p. 84)

The belief that true STEM education does not occur until later years is a hot topic among researchers. What is the best time to introduce integrated STEM education models into students' formal education?

McClure (2017) argued that early STEM programming, particularly from birth to eight years old, is just as important as early literacy in the practice of critical thinking, persistence, and systematic experimentation. Being naturally born scientists, students are "never too young for STEM" (McClure, 2017, p. 84). She argued, "young children can make observations and predictions, carry out simple experiments and investigations, collect data, and begin to make sense of what they found" (McClure, 2017, p. 84). A two-year research analysis among preschoolers determined these young learners can carry scientific practices using the scientific method matching that of high schools (McClure, 2017). She further commented that early STEM foundations are just as important as early literacy with both of these emerging skills predicting future academic achievement (McClure, 2017). Christensen et al. (2015) supported the importance of early STEM literacy claiming students are at a critical age in their early years for developing attitudes toward STEM education and the exploration of future STEM-based careers.On the opposite side of the grade-level spectrum, some researchers and experts providing integrated STEM education feel high school is a particular impactful time to introduce STEM learning models. Barakos et al. (2012) explained many current STEM programs are beginning at the high school level. The North Carolina New Schools Project has redesigned over one hundred high schools with the goal of every student graduating "ready for college, a career, and life" (Barakos et al., 2012, p. 5). Most of these schools have the specific purpose of explicitly teaching high school students using integrated STEM instruction, project-based learning, real-life issues, and collaboration. These researchers view STEM-focused high schools as the most effective route to generating students' interests in STEM fields and preparing them for STEM-related careers (Barakos et al., 2012).

Recently, inclusive STEM high schools (ISHS) have emerged in states across the country, such as California, Massachusetts, Texas, and Ohio. These exclusive STEM-focused secondary schools accept students based on interest and not on achievement or aptitude (Spillane et al., 2016). Although the practice of choosing students based on STEM interest is a powerful method of recruiting invested students, it can further decrease the number of females and underrepresented populations. For this reason, many ISHS intentionally recruit a larger proportion of minority groups often underrepresented in other STEM-related high schools. ISHS are showing promise in "deepening student understanding of STEM, bolstering their confidence, and allowing them to see new opportunities for college and career" (Spillane et al., p. 59).

The argument among researchers is not whether integrated STEM education is effective at the elementary, middle, or high school level, but rather which grade level is the introduction of STEM practices the most impactful on student achievement and, subsequently, future success. Both the elementary and high school years have been shown to be powerful in regard to shaping students' perceptions of their learning and impact on the development of integrated STEM education practices. Somewhere between the two may be the "goldilocks" zone, the middle school years, when students are beginning to develop attitudes and beliefs regarding their abilities in STEM and possibilities of future careers (Christensen et al., 2015). Lounsbury (2010, p. 52) recommended integrated STEM curriculum and instruction at the middle school level as it "provides opportunities for more relevant, less fragmented, and more stimulating experience for learners", with studies finding the integration of mathematics and science having a positive influence on student's attitudes toward school, their motivation to learn, and academic performance. Moreno et al. (2016) remarked, "The middle school years are a crucial time for cultivating students' interest in and preparedness for future STEM careers" (p. 889). Middle school is a pivotal time for students as their viewpoints on education and careers are greatly impacted by their environment and their focus shifts to future careers.

Cohen (2020) stated there are five reasons for introducing integrated STEM education at the middle school level. First, student's academic interest tends to wane in the middle school years with many students who enjoy school losing interest in traditional schooling. Integrated STEM education revives many students' interest in school subjects. Second, many students begin to form career aspirations in the middle school years. The project-based learning methods and real-life application involved in integrated STEM education assist students with future career exploration. Cohen (2020) stated, "Exposure to STEM careers during this time triggers students to seriously consider jobs in engineering, technology, manufacturing, biology, etc." (para. 3). Third, integrated STEM education often facilitates hands-on learning which wanes in the middle school years with an increase in long lectures and many subjects taught in isolation. Fourth, STEM training teaches problem solving which is particularly important in the middle school years as subjects begin to be taught in isolation. Lastly, integrated STEM education assists with closing the gender gap by exposing STEM principals to both males and females before making definitive decisions regarding future careers (Cohen, 2020).

Currently, there is no definitive research stating that integrated STEM education is not impactful nor important at a certain grade level. However, there are many reasons stating the particular importance during the middle school years, otherwise known as the "goldilocks" zone. This further supports the exposure of integrated STEM education during middle school and a pertinent factor in the proposed research study.

Project-based Learning (PBL)

The interdisciplinary and transdisciplinary approach to teaching integrated STEM education naturally enforces the use of PBL in the classroom. PBL solidifies the overlap of science, technology, engineering, and mathematics (Hansen & Gonzalez, 2014). PBL utilizes many of the best practice STEM attributes listed by Morrison (2016), such as creating an active and student-centered classroom and serving students with a variety of learning styles. The use of project-based instruction allows students to represent, model, and apply their content knowledge in interesting and unique ways (Wilhelm, 2014). In addition, Behizadeh (2014) stated the increasing importance of PBL to counteract the growing amount of high-stakes state assessments and increasing standardization. This allows students to participate in authentic instruction and provides an inquiry-based teaching experience for students (Behizadeh, 2014). Many researchers agree that PBL learning practices are highly effective as a method of teaching STEM education (Behizadeh, 2014; Hansen & Gonzalez, 2014; Morrison, 2016).

Bybee (1997) proposed five aspects of the learning cycle as a roadmap for using PBL as a method of instruction of STEM curriculum. Most STEM education curriculums like PLTW and EverFi, and PBL programs like the All American Soap use the five aspects of the learning cycle developed by Bybee as a foundational learning model derived from constructivist theory. The five aspects of the learning cycle theory are: engagement, exploration, explanation, elaboration, and evaluation. Engagement involves posing the problem to students, ensuring they make connections to previous learning, and pre-assessing existing knowledge. During the exploration phase students actively collect data. Explanation occurs when students apply their collected data to the research problem, make connections with their learning, and bring in new knowledge and vocabulary words. The fourth phase, elaboration, involves students presenting and actively applying their new learning to the research problem. This occurs in conjunction as the teachers present new challenges which require critical thinking to solve. Lastly, the evaluation phase assesses students' learning, not necessarily in a pencil-paper test, but through presentation of the research problem and solution and final outcomes of the project (Bybee, 1997). Bybee's (1997) proposed five-step PBL model is used today in many STEM activities and purchased curriculums.

History of STEM Education

There are many historical events that led to the development of STEM education. The Morrill Act of 1862, which granted land to universities for the development of agricultural training, eventually spawned the development of the first engineering-based training programs. For example, Ohio State University was initially called the Ohio Agricultural and Mechanical College (White, 2014). According to White (2014), land grant establishments began to develop and the concept of engineering based training formed into career and technology training and the creation of vocational high schools.

The other two historical events discussed by Gonzalez and Kuenzi (2012) and Hansen and Gonzalez (2014) that facilitated the development of STEM education were World War II and the Soviet Union's launch of Sputnik 1. World War II brought increased research into advancing technologies with academic researchers, scientists, and the military working in collaboration to aid in the war effort and consequently propelling STEM education (Gonzalez & Kuenzi, 2012). The Soviet Union's launching of Sputnik 1 in 1957 began the Space Race. The United States and the Soviet Union were suddenly in competition to win the lead in the advancement of worldwide technology, STEM education, and, ultimately, global control (Gonzalez & Kuenzi, 2012; White, 2014). Gonzalez and Kuenzi (2014) reported that this scared the United States by motivating them to push for technological advancement and the improvement of STEM education, with Congress passing the "Space Act" in 1958 forming NASA and the federal government's response with the formation of NDEA. The mission of NASA was to "expand and improve" the presence of the United States in space and maximize the use of science and engineering to complete that endeavor (White, 2014, p. 3). All of these events were pivotal in the creation and sustainment of STEM education.

In 1983, *A Nation at Risk* was published as an educational reform policy reviving the STEM movement in public education (Mahoney, 2009; Mahoney, 2010). Mahoney (2010) reported *A Nation at Risk* was extremely influential in the development of national standards produced by the National Council of Teachers of Mathematics (NCTM), the National Research Council (NRC), the International Technology Education Association (ITEA) and the American Association for the Advancement of Science (AAAS). These interest groups were pivotal in the advancement of science, technology, engineering, and math both as individual subjects and combined as STEM education (Mahoney, 2010).

In addition, the No Child Left Behind (NCLB) revived legislation of the Elementary and Secondary Education Act (ESEA) and reinstated Title 1 including disadvantaged students to the provisions. NCLB supported educational reform through standards-based education following a path of high standards and goals measured through state assessed basic skills. The caveat to receive federal funding under NCLB and, subsequently, Title 1 is that all schools must administer state assessments to students in certain subjects and specific grade levels (U.S. Department of Education, 2004).

In 2015 the U.S. passed the Every Student Succeeds Act (ESSA) taking away some control from the federal government in public education evident in NCLB. Under this renewed federal law, more power and decision-making latitude were given to local school districts and states, including the use of funding, particularly under Title IV (Achieve, 2017; ESSA, 2017). The passage of ESSA has given local school districts the abilities and funding to provide formal STEM programming, digital literacy curriculum, and the purchasing of technology.

In 2019, two bills were passed through Congress further enhancing public education's ability to provide STEM programming to meet the needs of all students, including underrepresented populations. The *STEM Research and Education Effectiveness and Transparency Act* was passed in January 2019 allowing for broadening participation in National Science Foundation (NSF) research and educational programs including STEM education (STEM Research and Education Effectiveness and Transparency Act, 2019). The second bill, the *21st Century STEM for Girls and Underrepresented Minorities Act*, passed in May 2019, provides grants to local educational agencies to empower girls and other underrepresented minorities to participate in STEM programs and pursue STEM field careers (21st Century STEM for Girls and Underrepresented Minorities Act of 2019, 2019). All of these events and policies have shaped and modeled STEM education into what it is today.

STEM Education in Ohio, Pennsylvania, and West Virginia

Many economic and geological factors shaped the state of STEM education in the area known as the Appalachia Partnership Initiative (API) area. The API area consists of 27 counties within Ohio, Pennsylvania, and West Virginia known for producing the majority of natural gas in the nation and the primary location of the Marcellus and Utica Shales. Ironically, this area known as the “rust belt” saw significant economic decline and deindustrialization beginning in the 1970s due to the decline in steel production (Crandall, 1993). However, with the resurgence of natural gas through hydraulic fracking in the API regions the “rust belt” is in an economic upswing. Due to the vast amount of fossil fuels and STEM-related labor and manufacturing jobs in the API region, there is a tremendous need for STEM education and workers. In 2017, the Rand Corporation completed a report on employment in energy and advanced manufacturing–related industries and on various indicators of effective STEM education (Gonzale et al., 2017).

The majority of natural gas production occurs within two geographical regions: the Marcellus Shale that includes Ohio, Pennsylvania, West Virginia, New York, Maryland, and the Utica Shale, with the majority of production in Ohio, Pennsylvania, and West Virginia, respectively (Gonzalez et al., 2016). This has created a significant rise in the number of middle-skilled workers needed to fill positions in the energy industry (Gonzalez et al.) with the nation unable to fill many of the current STEM-related positions (Atkinson, 2012; Gonzalez & Kuenzi, 2012; Gonzalez et al., 2017).

The Appalachia Partnership Initiative (API), launched in 2014 by the Social Investment Team of the Chevron North America Appalachian/Michigan Business Unit, was created with the primary and long-term goal of preparing and training local workers for careers in the energy and advanced manufacturing regions within the Marcellus and Utica Shale areas (Gonzalez et al., 2016; Gonzalez et al., 2017). The API is devoted to investing $20 million into STEM education from kindergarten to 12th grade dispersed among 27 counties in Ohio, Pennsylvania, and West Virginia (Gonzalez et al., 2016). According to Gonzalez et al. (2016), they are also committed to developing STEM workforce development programs along with other stakeholders, such as public schools, training institutions, industry, and nonprofit entities. This is in order to increase preparedness, hands-on training, and skills necessary to meet the demands of jobs in the energy and advanced manufacturing fields (Gonzalez et al., 2016).

The API has collected a considerable amount of data related to STEM education, workforce development, wages, and employment trends all gleaned internally or from outside sources, such as the U.S. Census Bureau, National Assessment of Educational Progress (NAEP), the U.S. Department of Education's National Center for Educational Statistics Integrated Postsecondary Education Data System (IPEDS), and the Department of Education for each state (Gonzalez et al., 2016; Gonzalez et al., 2017). There were four key findings reported by the API that are important given the scope and research of this literature review. First, although many counties within the API region are decreasing in population, the overall number of people in the 27 county region is unchanged due to significant growth in a number of counties. Second, workers in STEM fields received the highest pay in the regions. However, the average pay for STEM workers in the region was below the national average for STEM workers with the same education and experience. Third, the API states of Ohio, Pennsylvania, and West Virginia, saw an increase in graduation rates matching the national trends. West Virginia, however, was behind the national averages in student math and science achievement. Fourth, the Rand Corporation determined that institutions of higher education were educating students in majors able to fill the needs of local employers in the STEM workforce (Gonzales et al. 2016; Gonzalez, et al., 2017).

According to Gonzalez et al. (2017), the main conclusion from the API research was that the region is producing and sustaining local STEM workers higher than the national average. However, they did find the number of workers able to work as determined by age is decreasing. They also found Ohio and Pennsylvania graduate more high school students who enter STEM fields in their careers or college majors than the national average, with West Virginia lagging behind. The API determined Ohio, Pennsylvania, and West Virginia are ahead of the nation in preparing students to enter the workforce. They are also leading the nation in the percentage of STEM-related associate's degrees and certificate programs. In addition, they found the number of workers of working age is decreasing with no evidence that there is enough supply to meet the upcoming and current demand of jobs in the energy and advanced manufacturing fields (Gonzalez et al., 2016; Gonzalez et al., 2017).

Funding for STEM Education

Along with the API, there are several funding sources for a number of recent STEM education initiatives. Gonzalez's and Kuenzi's (2012), *Specialist in Science and Technology Policy* and *Specialist in Education Policy*, respectively, reported four inventories in STEM education mandated by Congress with "three of the four agencies making up four-fifths of federal funding in STEM education. These three agencies are: the NSF, the Department of Education (ED), and the Department of Health and Human Services (HHS)" (p. 4). A third of all federal funding reserved for STEM education is appropriated to the NSF with the majority of the funding spent on student degree attainment, research, and the development of STEM careers (Gonzalez & Kuenzi, 2012). The National Science Foundation's Innovative Technology Experiences for Students and Teachers (ITEST) program has continued to support kindergarten through 12^{th-}grade students and teachers in providing STEM-based activities with the goal of creating STEM career pathways (Connors-Kellgren et al., 2016).

The previously discussed renewed ESSA Act in 2015 gave more power, funding, and decision-making abilities to local school districts and states, particularly under Title IV (Achieve, 2017; ESSA, 2017). Title IV provides funding for 21st-century initiatives, Student Success and Academic Enrichment (SSAE) Grants, and after school enrichment programs. According to ESSA, beginning in 2017, $1.6 billion were given to districts under the SSAE Grants with the intention of improving student academic achievement. Using similar funding determinations as Title I, districts can use the support to improve the use of technology, including STEM education and digital literacy to increase student achievement (ESSA, 2017). Under ESSA, there are several activities and programs supported by Title IV with the intention of providing students with a well-rounded education. ESSA supports the expansion of high-quality STEM courses and increases access to STEM students in at-risk and underserved groups. ESSA also ensures that students get support in nonprofit STEM competitions and programs allowing for hands-on opportunities for students. The act supports the integration of other academic subjects, such as social studies, as well as the arts into STEM programs. ESSA seeks to support the integration of informal, integration programs and afterschool STEM programs also assisting with environmental education (ESSA, 2017).

The increased funding for 21st-century programming, including STEM education, provided by the passage of ESSA has created a demand for high-quality STEM curriculum and programming. The passage of ESSA has sparked national interest in the STEM disciplines. This has created the realization of the importance of development and innovation of STEM education, making this a critical component of recent educational reform. In addition, the support from ESSA for the integration of content subjects, such as science and mathematics into both formal and informal STEM instruction has further promoted the push for integrated STEM education (Achieve, 2017).

Post-secondary Education and Career Readiness

Gonzalez and Kuenzi (2012) reported more than half of federal funding reserved for STEM education is appropriated for undergraduate, graduate, and career-based training education and research. A considerable amount of this funding is used for remediation programs and to increase retention rates in STEM fields and career-based programs (Gonzalez & Kuenzi, 2012). The primary motivation of remedial programs is to fill the demand for jobs in the STEM fields, such as mathematicians, scientists, and engineers.

The majority of students in STEM programs at the post-secondary and college level continue to perform at or below basic proficiency levels (Stieff & Uttal, 2015). According to Gonzalez et al. (2017) and Rand Corporation research, higher education institutions are doing an effective job at preparing college students for the local STEM workforce. However, Han and Buchmann (2016) reported half of all college students majoring in a STEM field leave the field before graduation and pursue a different degree field. The lack of perseverance and academic underperformance of STEM students at the college level has created a need for research regarding the academic performance and achievement of students in middle and high school.

Implications for Educational Leaders

There are many implications for educational leaders regarding their role in the development and implementation of STEM programming. The role of educational leaders has become increasingly significant due to the recent political power shifting to local school districts and increased funding, such as those mandated by ESSA (Achieve, 2015; ESSA, 2015).

Research on the challenges of STEM education reform at the kindergarten through 12th-grade level most often focus on the important role of teachers and students (National Research Council, 2011). The beliefs and attitudes of teachers and students are found to be most influential (McGinnis et al., 2002). Many studies regarding the impact of collective teacher efficacy and student self-efficacy refer to the strong influence of teacher and student beliefs as an indicator of student achievement and success (Donohoo, 2007; Hattie, 2009).

Although teacher and student attitudes and beliefs play an important role in shaping all general education reform, Bybee (2013) discussed the major challenges specific to STEM education. He stated these are related to the misunderstandings surrounding the definition of STEM education and the qualifications of STEM literacy. The themes related to reform according to Bybee (2013) include: focusing on global challenges with citizen understanding, changing societal views of environmental issues, identifying 21st-century skills in the workforce, and challenges facing national security. School leaders play an important and foundational role in ensuring the implementation and sustainability of STEM reform (Bybee, 2013; Waight et al., 2018).

Expanding on the prior research of Bybee (2013), Waight et al. (2018) identified five main components regarding the role of educational leaders tackling STEM reform. First, leaders must engage in active student recruitment for STEM programs. Second, educational leaders must facilitate school and community-based activities. Next, leaders must make students aware and prepare them to contribute to the local economy. Additionally, they must solve administrative and logistical issues. Lastly, educational leaders must provide effective professional development for teachers. All of these themes of an effective educational leader are imperative to the success of STEM reform and program development (Waight et al.).

In 2010, President Obama’s Council of Advisors on Science and Technology (PCAST) prepared a report with five recommendations for educational leaders and stakeholders. These recommendations are necessary to improve STEM education with the main goal of preparing and inspiring future students into joining STEM fields (Kennedy & Odell, 2014). There are five recommendations by PCAST and they are described by Kennedy and Odell (2014). The first recommendation is to improve federal coordination and leadership on STEM education. This is an important implication for educational leaders previously discussed by Waight et al. (2018). The second recommendation is for leaders to support the state-led movement to create a common benchmark for student learning in STEM. This is related to the creation of national standards and curriculum that is needed in STEM education. Third, is to foster, recruit, and reward teachers for inspiring and preparing students to pursue STEM careers and higher education. The fourth recommendation for leaders is to create STEM-related experiences to increase students' interest. Fifth, policymakers and stakeholders need to support states and local school districts in creating STEM education reform (PCAST, 2010). According to Kennedy and Odell (2014), the purpose of these recommendations for educational leaders and stakeholders is to ensure achievement in three goals of K-12 STEM education; to expand the STEM workforce, to increase technological and STEM literacy, and to improve advanced training and career preparedness (p. 249).

Impact on Student Achievement

The impact of STEM education policies and initiatives on student achievement report varying degrees of success (Dugger, 2010; Gonzalez & Kuenzi, 2012; Snyder, 2018; White, 2014). Gonzalez and Kuenzi (2012) attested there is no single statistic that can fully quantify or encompass the condition of STEM education in the nation and for a variety of reasons the question "what is the condition of STEM education?" may be unanswerable" (p. 9). Many researchers and experts note that it is difficult to determine the extent STEM education has impacted students. Although, from a broad perspective, STEM education has maintained or improved its impact over the past 40 years. Gonzalez and Kuenzi (2012) commented that it is difficult to measure the success of the United States educational system due to its complexity.

In 2019, the most comprehensive report of the current state of student achievement in relation to STEM education was published by the National Science Board, titled *Science and Engineering Indicators 2020*. This federally funded government report found the United States ranks in the middle among 19 advanced nations in student performance in the STEM fields of science, technology, engineering, and mathematics. STEM students in the U.S. are underperforming compared to students in other developed countries such as Singapore, Taiwan, and South Korea (National Science Board, 2019).

Nationally, U.S. students' achievement in mathematics has increased in the last 30 years with the largest growth occurring in the first two decades (National Science Board, 2019). Figure 1 illustrates students' academic achievement in mathematics measured by performance on the

National Assessment of Educational Progress (NAEP), the largest nationally recognized assessment used for representative sampling to determine performance of all students nationally. Average mathematics scores of 8th-grade students have grown since 1990 with improvement slowing in the past 10 years with an average mathematics score of 281 in 2007 and 283 in 2017, respectively (National Science Board, 2019).

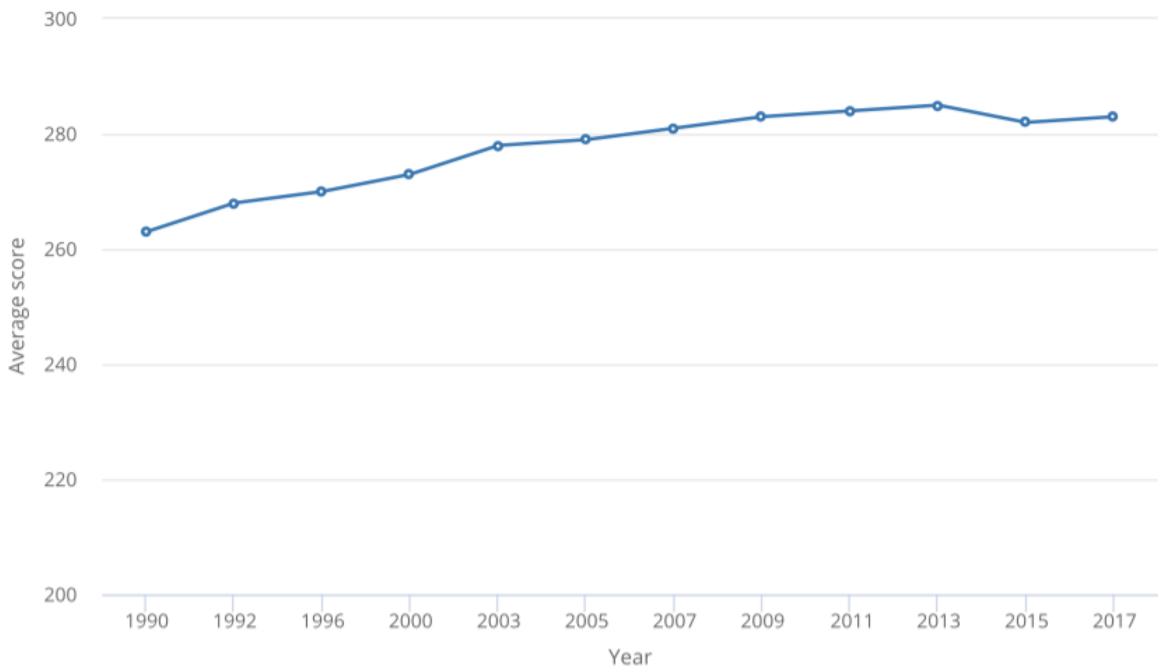
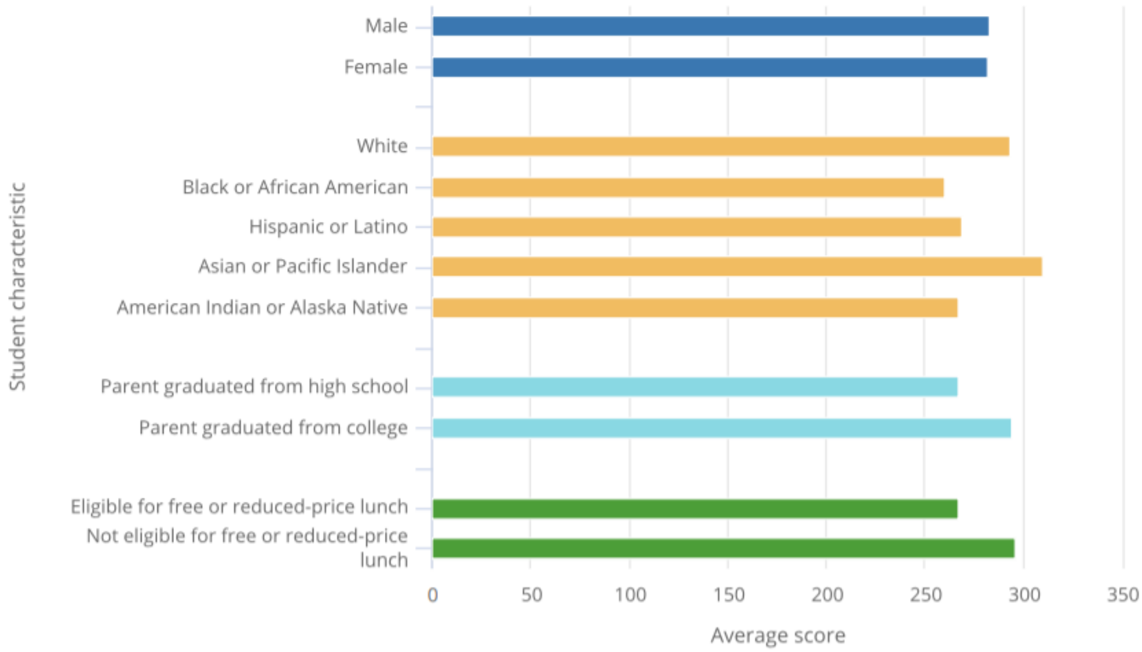


Figure 1. Average NAEP Mathematics Scores of Students in Grade 8: 1990-2017, 2019

Note. The scale for NAEP mathematics assessment scores is 0-500 for grade 8

Student mathematics achievement as evidenced by NAEP scores vary greatly according to student demographics. Figure 2 displays the important findings related to gender, student race, parent educational level, and socioeconomic status (SES). Male students outperform females with an average score, in 2017, of 283 for males versus 282 points for females. Although this appears as a small difference, it is statistically significant given such a large sample size with greater than 11,000 students per year (National Science Board, 2018). Student race shows large disparities in mathematics achievement with Asian or Pacific Islander students earning 310 points and White students achieving 293 points. Hispanic populations averaged 269 points. Lastly, Black or African Americans earned only 260 points on average, some 50 points behind the achievement in the Asian and Pacific Islander population (National Science Board, 2019).



NAEP = National Assessment of Educational Progress.

Note(s)

The scale for NAEP mathematics assessment scores is 0–500 for grade 8. Hispanic may be any race; race categories exclude Hispanic origin.

Figure 2. Average Scores of Students in Grade 8 on the NAEP Mathematics Assessment, by Student Characteristics: 2017, 2019

Note. The scale for NAEP mathematics assessment scores is 0-500 for grade 8. Hispanic may be any race; race categories exclude Hispanic origin

According to the National Science Board (2019), students whose parents graduated from college showed statistically higher achievement than students whose parents only graduated from high school. This large difference in math performance was also grossly evident according to SES among students. SES was determined by the eligibility of students in the National School Lunch Program (NSLP). The achievement gap between students in the low-SES category has been consistently 26-30 points below students in the high-SES category for the entire duration of the 21-year study.

Figure 3 illustrates the achievement gap between students eligible for free or reduced-price lunch (low-SES) and not eligible for free or reduced-price lunch (high-SES).

Figure 3. Average NAEP Mathematics Scores of Students in Grade 8, by Eligibility for National School Lunch Program: 1996-2017, 2019

Note. NAEP uses eligibility for the federal National School Lunch Program (NSLP) as a measure of socioeconomic status

NSLP is a federally assisted meal program that provides low-cost or free lunches to eligible students. It is sometimes referred to as the free or reduced-lunch program. Information on students' eligibility for free or reduced-price lunch was first collected in 1996.

There is a significant achievement gap in NAEP mathematics scores among various underrepresented populations as evidenced by the National Science Board (2019). To determine technological and engineering literacy, the National Science Board administered the NAEP Technology and Engineering Literacy Assessment with students' average performance increasing every year since 2014. However, little subgroup data on underrepresented populations have been conducted on technology and engineering achievement (National Science Board, 2019). In order to gain a better perspective into the state of STEM education, this study will analyze performance and academic achievement for subgroups of students such as women, minorities, and other underrepresented populations compared to the general education population.

STEM Careers and Workforce Development

The National Science Board (2019) concluded students taking high school STEM courses or who had exposure to STEM-related programs were more likely to get a STEM-related job in the workforce directly after high school or take technical education courses to gain the skills to get a technical job. However, similar to academic achievement, there are large disparities among underrepresented groups participating in STEM careers and in the workforce (Gonzalez & Kuenzi, 2012; Hebebci, 2019; Kennedy & Odell, 2014; National Science Board, 2019; Funk & Parker, (2018a).

Underrepresented Groups

An ongoing trend reported by many researchers is the increasing achievement gaps among underrepresented groups such as minorities, women, and economically disadvantaged students (Beede et al., 2011; Gonzalez & Kuenzi, 2012; Kennedy & Odell, 2014; Sanders, 2009; National Science Board, 2019). Gonzalez and Kuenzi (2012) stated that these gaps in STEM achievement are evidenced by several data sources, such as test scores, degree acquisition, and employment in STEM-related careers. Gonzalez and Kuenzi (2012) argued underrepresented groups are an untapped resource for potentially filling many STEM-related positions currently needed in the workforce. They explained that the exposure to STEM and increase in participation in STEM fields among women and racial minorities may pose a solution to the labor shortage issue described by Kennedy and Odell (2014) and Gonzalez et al. (2017) in their review under the API.

Contrarywise, Gonzalez and Kuenzi (2012) and Kennedy and Odell (2014) cited that science and engineering enrollments have grown by 35% in the past decade with Hispanic, American Indian, and African American students increasing by 65%, 55%, and 50%, respectively. In 2021, the largest increase in U.S. student enrollment is expected to occur among bilingual Hispanics, necessitating a future demand for bilingual STEM education (Kennedy & Odell, 2014). The study of underrepresented populations within STEM fields is a popular area of research. Banning and Folkestad (2012) concluded in their meta-study reviewing 101 dissertations that recruitment and retention of underrepresented students in STEM-related fields was a major topic among researchers over the span of their 20-year study.

In more recent years, inclusive ISHS in Texas, North Carolina, Tennessee, and Ohio have developed with the main focus of recruiting and retaining higher ratios of underrepresented students, particularly African-Americans, economically disadvantaged students, women, Hispanics, and first-generation college students (Spillane et al., 2016). The mission of ISHS is to prepare students in underrepresented populations, focusing on minorities, for success in STEM-related fields and college majors (Lynch et al., 2018; Spillane et al.). Ultimately, ISHS assist with lowering the achievement gap among minorities and other underrepresented populations (Lynch et al.; Spillane et al.).

Despite the increased demand to fill jobs in the STEM fields, such as mathematicians, scientists, and engineers, the majority of students in STEM programs at the post-secondary and college level continue to perform at or below basic proficiency levels (Stieff & Uttal, 2015). Students in middle school, nationally, are underperforming as evidenced by the majority of eighth grade students scoring below basic levels on the NAEP science test. Researchers conclude that U.S. students are receiving inadequate academic instruction in STEM education (Etim, Etim, & Blizard, 2020; Stohlmann et al., 2011; National Science Board, 2019). Although the demand for STEM professions is at an all-time high, the number of STEM college graduates is low and not meeting the national demand with not enough students choosing to major in a STEM field and even disproportionately less minorities and women are choosing the career field (Doerschuk et al., 2016; Gonzalez & Kuenzi, 2012; Funk & Parker, (2018a). The underperformance of STEM students beginning in kindergarten through high school and beyond has created a need for further research regarding academic performance and achievement.

Gender

A decade ago, it was reported that women earned more college degrees than men, however, at the time they also held less than one quarter of the STEM-related jobs in the nation (Beede et al., 2011; Gonzalez & Kuenzi, 2012). More recently, Funk and Parker (2018a) announced the share of women working in STEM occupations had increased and is about half, matching men in the number of STEM workers. Figure 4 displays the representation of women in STEM jobs illustrating the gender differences in STEM careers varies greatly depending on the area of STEM career.

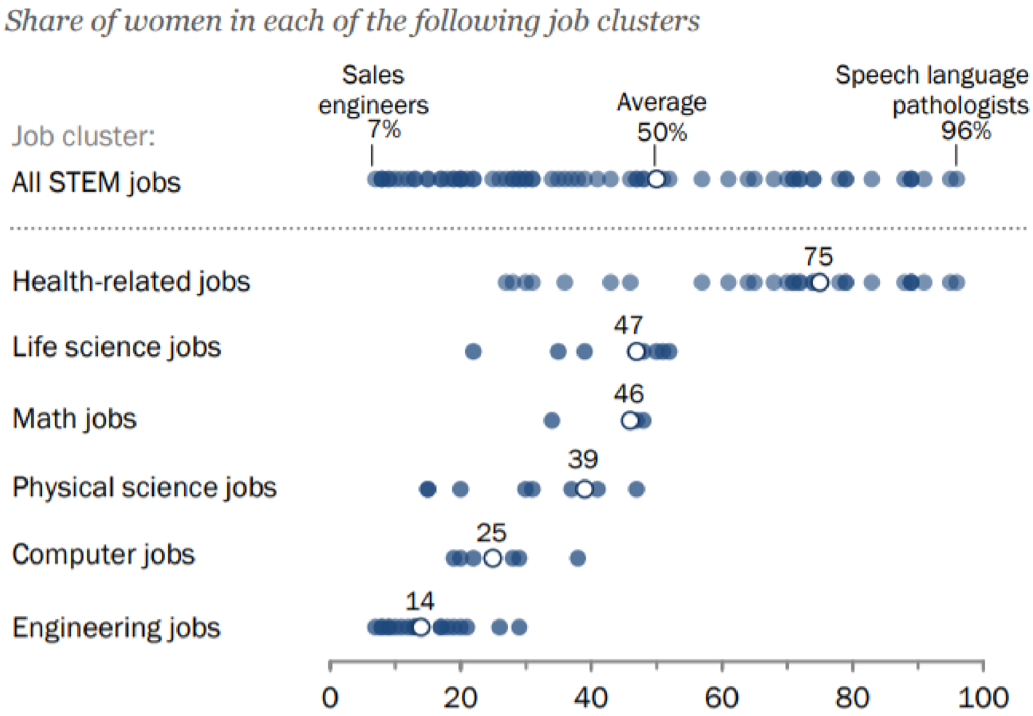


Figure 4. Representation of Women in STEM Jobs Varies Widely

Note. Based on employed adults' ages 25 and older. Each circle represents a single occupation (e.g., mechanical engineer, registered nurse). Engineering includes architects.

Women make up 96% of speech language pathologists and 95% of dental hygienists, respectively. Conversely, women encompass less than 10% of sales engineers and only 8% of mechanical engineers (see Figure 4). For computer occupations, which has experienced the greatest growth in available jobs in recent years, women's representation has decreased from 32% in 1990 to 25% in recent years (Funk & Parker, 2018a). The representation of women in STEM careers appears highly dependent upon the STEM job cluster. The causes for the underrepresentation of women among particular STEM job clusters is debated among researchers (Beede et al., 2011; Gonzalez & Kuenzi, 2012; Shapiro et al., 2015). Some state the reasons are due to self-efficacy, discrimination, school culture, and the bias of girls participating in science (Gonzalez & Kuenzi, 2012). Others attribute this phenomenon to the influence of family and upbringing, with women continuing their roles as primary caregivers, maintaining society's expectations influencing career choices (Gonzalez & Kuenzi, 2012), a lack of women role models, gender stereotyping, and a more difficult work/life balance in STEM career fields (Beede et al.). Shapiro et al. were surprised by these findings because girls currently perform better academically than boys in high school with average GPAs of

3.42 and 3.28, respectively. Shapiro et al. called the decreasing number of girls, as they advance through school participating in leadership positions and STEM fields, the "leaky pipeline" (Shapiro et al., p. 3). The leaky pipeline of women into leadership roles and STEM-related careers is evident with women taking on more traditional female-dominated, or "pink collar" jobs, such as nursing, education, or retail sales (Maltese & Tai, 2011, p. 877; Shapiro et al., p. 3). Although described in different ways, this phenomenon is evidenced among many researchers (Beede et al.; Gonzalez & Kuenzi, 2012; Maltese & Tai, 2011; Funk & Parker, 2018a; Shapiro et al.; Spillane et al., 2016).

Minority Students

Black and Hispanic students are greatly underrepresented in STEM careers and jobs in the workforce in relation to all U.S. occupations. In 1990, Blacks made up 7% of STEM workers and increased to a mere 9% by 2018. Hispanics filled just 4% to 7% in the same time period. In contrast, Asians are overrepresented in relation to the number of total workers with over 17% being both college-educated and STEM workers. Figure 5 illustrates the underrepresentation of Blacks and Hispanics across many clusters of STEM careers.

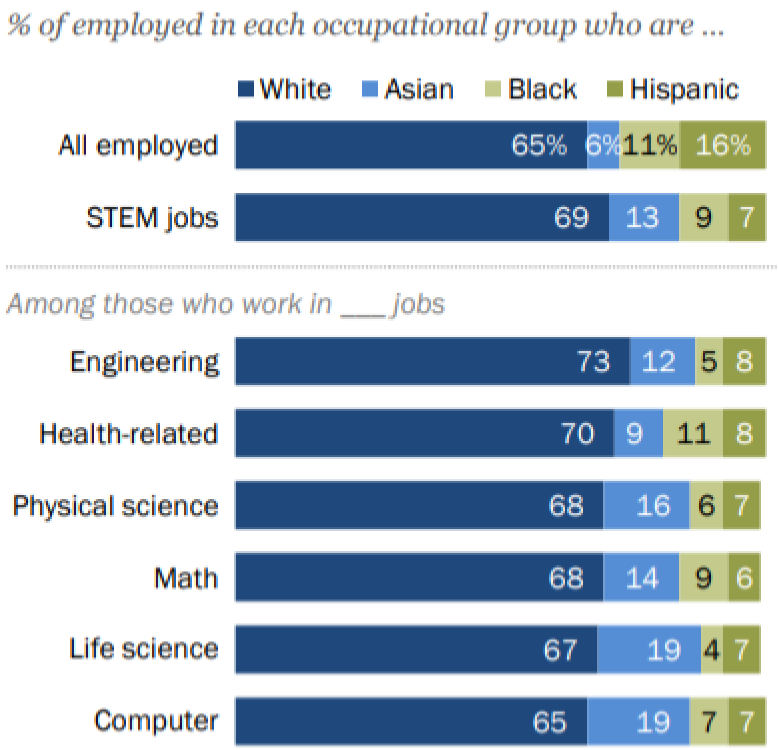


Figure 5. Blacks and Hispanics Underrepresented across Most STEM Job Clusters

Note. Based on employed adults' ages 25 and older. Whites, Blacks, Asians include only non-Hispanics. Hispanics are of any race. Other and mixed-race non-Hispanics are not shown. Engineering includes architects.

According to the Funk and Parker (2018b), health technicians and nursing positions have the largest proportion of Black and Hispanic workers. Thirty-seven percent of medical technicians and vocational nurses are either Black or Hispanic, while only 17% of registered nurses are Black. The most recent data state the percent of STEM workers is as follows (See Figure 5): White (69%), Asian (13%), Black (9%), and Hispanic (7%). There is a large disparity between different STEM job clusters among minorities (Funk & Parker, 2018b; Gonzalez & Kuenzi, 2012).

The underrepresentation of minorities in the STEM workforce is a direct byproduct of the achievement gaps evident among minorities in kindergarten through high school graduation (Gonzalez & Kuenzi, 2012). Gonzalez and Kuenzi (2012) commented researchers have identified dozens of variables responsible for the achievement gap in STEM-related fields among minority populations, such as lack of parental involvement, lower socioeconomic status (SES), "a lack of resources (underfunding) and less qualified teachers at schools that serve minority students, teachers' low expectations, stereotype threat, and racial oppression" (p. 24). They reported at least a 20-point decrease in African American and Hispanic students compared to White students on the 4^{th-} and 8^{th-}grade NAEP in 2011 (Gonzalez & Kuenzi, 2012) and in 2017 (National Science Board, 2019). The *2011 Review*, produced by Gonzalez and Kuenzi (2012), lists many factors that positively and negatively influence minority students' preparedness in STEM education. The positive factors are: parental support and involvement, early age introduction to STEM, self-efficacy in STEM subjects, exposure to STEM-related activities, and opportunities for bilingual STEM education. The negative factors include: lack of resources due to underfunding, teachers in schools with a large proportion of minority students under-qualified in STEM fields, limited advanced placement classes, low expectations from teachers, bias and stereotypes among minorities, and a higher dropout rates (Gonzalez & Kuenzi, 2012). The many factors responsible for the achievement gap in STEM education among minorities is a complex, multi-faceted issue fueling much of the research within this study.

Curriculum and Standards

Currently, in the U.S., there are no nationally-recognized standards for STEM education, nor are there any for the state of Ohio. Han and Buchmann (2016) stated the lack of curriculum standardization in the U.S. has contributed to lower science achievement and most likely other disciplines in STEM, as well. The lack of continuity and standards in STEM education has stimulated the National Research Council (NRC) and the National Academies of Engineering to highlight the need for intentional and explicit instruction of STEM curriculum and standards (Radloff & Guzey, 2016).

Despite the lack of current STEM standards, there are *Standards for Technological Literacy (STL)* developed by the ITEA, 2000/2002/2007). The most recent STL version was released in 2007. The ODE released the *2017 Ohio Learning Standards in Technology,* updating the 2003 learning standards. This divided technological education into three main disciplines: Information & Communication Technology, Society & Technology, and Design & Technology (ODE, 2019).

Many non-profit providers have developed STEM curriculum intended to be used in public education. Two of these are reviewed in literature: PLTW and The Infinity Project (Stohlmann et al., 2012). PLTW, the nation's largest non-profit STEM curriculum for middle and high schools is increasingly used today in classrooms but little research has been conducted on its impact on student achievement and future career choices (Berland, 2013). Lawanto et al. (2012) researched the relationship between interest and success expectancy in STEM careers for students taking a PLTW Engineering Design course. Lawanto et al. determined there was a significant relationship between student self-interest in engineering design and their expectancy for success with intrinsic motivation being a predictor of future success and choice of STEM career.

Project Lead the Way

Due to the increase in national funding allocated to public schools, particularly under ESSA (2015), there has been an influx of engineering and STEM curriculums designed for middle school. Currently, the nation's leading STEM curriculum for middle and high school is Project Lead The Way (PLTW, 2020). PLTW is a nonprofit organization with the goal of providing an impactful interdisciplinary STEM curriculum for students in grades kindergarten through 12th grade (Stohlmann et al., 2011). PLTW focuses on STEM curriculum comprising areas of computer science, engineering, and biomedical science with the intention of improving problem solving, critical thinking, communication, perseverance, and creativity. PLTW is aligned to the Next Generation Science Standards and the Common Core State Standards for ELA and Math (PLTW, 2020).

The middle school program, PLTW Gateway, consists of 10 units designed to be taught daily for nine weeks (PLTW, 2020). Below are the 10 PLTW Gateway units with course descriptions:

Design & Modeling- Students discover the design process and develop an understanding of the influence of creativity and innovation in their lives. They are then challenged and empowered to use and apply what they have learned throughout the unit to design a therapeutic toy for a child who has cerebral palsy.

Automation & Robotics- Students learn about the history and impact of automation and robotics as they explore mechanical systems, energy transfer, machine automation, and computer control systems. Using the VEX Robotics platform, students apply what they know to design and program traffic lights, robotics arms, and more.

App Creators- This unit exposes students to computer science as a means of computationally analyzing and developing solutions to authentic problems through mobile app development and will convey the positive impact of the application of computer science to other disciplines and to society.

Computer Science for Innovators and Makers- Throughout the unit, students learn about programming for the physical world by blending hardware design and software development, allowing students to discover computer science concepts and skills by creating personally relevant, tangible, and shareable projects.

Energy and the Environment- Students are challenged to think big and toward the future as they explore sustainable solutions to our energy needs and investigate the impact of energy on our lives and the world. They use what they have learned to design and model alternative energy sources, as well as evaluate options for reducing energy consumption.

Flight and Space- The exciting world of aerospace comes alive through Flight and Space Students explore the science behind aeronautics and use their knowledge to design, build, and test an airfoil.

Science of Technology- Science impacts the technology of yesterday, today, and the future. In this unit, students apply the concepts of physics, chemistry, and nanotechnology to activities and projects, including making ice cream, cleaning up an oil spill, and discovering the properties of nano-materials.

Magic of Electrons- In this unit, students examine the behavior and parts of atoms as well as the impact of electricity on the world around them. They learn skills in basic circuitry design and use what they know to propose designs such as burglar alarms for an art museum.

Green Architecture- In this unit, students learn how to apply green concepts to the fields of architectural sustainability and apply what they have learned to design affordable housing using Autodesk's 3D architectural design software.

Medical Detectives- Students play the role of real-life medical detectives as they collect and analyze medical data to diagnose disease. They solve medical mysteries through hands-on projects and labs, measure and interpret vital signs, examine nervous system structure and function, investigate disease outbreaks, and explore how a breakdown within the human body can lead to dysfunction.

(PLTW, 2020)

All 10 PLTW Gateway units were taught as nine-week units in this study except for App Creators and Science of Technology. PLTW Gateway curriculum is intended to be taught along with the many components discussed earlier by Honey et al. (2014) as interdisciplinary, cross-disciplinary, and connected with no thorough boundaries separating each discipline. Morrison (2016) discussed several suggested attributes of an effective STEM classroom that follow the principles of PLTW for grades six through 12: active and student-centered, supportive of various modalities of learning, accommodating of many different learning styles and able to serve students with disabilities. Many of these attributes are also discussed by Bybee (1997) in his five steps of the learning cycle of PBL.

In addition, there are several technical and equipment-related attributes necessary for a successful STEM classroom (Morrison, 2016). These attributes are needed to ensure success in facilitating many of the PLTW Gateway modules discussed: classroom and laboratory are physically one, classroom furniture is easily moved and reconfigured, small tools and manipulatives are available, specific equipment readily available to support inquiry-based learning, and computers with the necessary software are readily available for students (Morrison, 2016).

The combination of teaching the traditional subjects of science, math, reading, and social studies, PLTW STEM units, in conjunction with the attributes described by Morrison (2016) and aspects of the PBL learning cycle proposed by Bybee (1997), create the integrated STEM model utilized in this study.

Isolation versus Integration

Dugger (2010) and Sanders (2009) explained many ways of teaching STEM in kindergarten through 12th grades. One method is to instruct STEM individually, teaching science, technology, engineering, and mathematics separately in "silos" as individual subjects (Dugger, 2010, p. 4), also known as teaching STEM in isolation. Stohlman et al. (2011) stated mathematics and science are the subjects most often taught in isolation. Another way is to teach all four subjects concurrently and interwoven together in an interdisciplinary method, called teaching STEM in integration (Dugger, 2010, p. 4). There are also ways discussed by Dugger (2010) that range in between teaching in isolation and integration, such as teaching STEM with an emphasis on certain subjects over others, like SteM which is the integration of technology and engineering in a primarily science and mathematics classroom. Dugger (2010) and Sanders (2009) noted more research needs to be conducted on the success and effectiveness of each of these models. Bhattacharya et al. (2015) performed and analyzed fully integrated STEM lessons and reported that it is very difficult for science teachers to design and facilitate engineering concepts into STEM lessons. Berland (2013), Honey et al. (2014), and McGinnis (2017) added full STEM integration, although powerful, has many challenges and more research in science and engineering education needs to be conducted. Locke (2009) created proposed models for streamlined and optimized STEM programming for kindergarten through 12th grades, containing an engineering focus. Locke's (2009) visionary models were created years before the influx of the integrated and interdisciplinary STEM movement and are used as a guide for STEM programming frameworks.

Some STEM for All or All STEM for Some

Atkinson (2012) discussed another dichotomy that exists in how STEM education is provided to students. Atkinson (2012) reported the majority of stakeholders believe all students should be exposed to STEM education in varying degrees and coined the "Some STEM for All" or "STEM for All" approach. Gonzalez and Kuenzi (2012) reported analysts argue that this is not successful. The opposite method argued by Atkinson (2012) to be more effective, particularly at the high school level, is providing intensive STEM education to a limited number of students, based primarily on student interest, and is called the "All STEM for Some" approach. The dichotomy of STEM-integration delivery into schools is a controversial topic with more research needed to determine what method is most impactful on students' success and achievement (Atkinson, 2010). In response to Atkinson's (2010) claims, Elrod et al. (2012) stated,

> In the same way that our society is the richer for developing a citizenry that appreciates good music whether or not each person develops into a professional jazz musician, our society is richer for cultivating the seedbed of STEM literacy (p. 13).

Elrod et al. argued that Atkinson's (2010) ideas to concentrate on providing STEM education to fewer students showing interest in the discipline reinforces the exclusivity and disparity of minorities and underrepresented groups. They concluded that Atkinson's (2010) model of "All STEM for Some" strengthens the STEM pipeline for a select few. However, providing all STEM for a few select students often excludes minorities and underrepresented groups. Many researchers consider this a major criticism or the "All STEM for Some" approach to providing STEM education (Elrod et al, p.11). Further research must be conducted to determine the effectiveness of both STEM integration approaches. This study will add to the current research on the impact of STEM integration on student achievement.

Education Pathways and Future Careers

There is a reported decline in student interest in STEM fields as students advance from middle to high school. Students are noted to view STEM careers as uncreative and socially isolating (Kier et al., 2014; Doerschuk et al., 2016; Simon et al., 2015). Kier et al. argued that to maintain the momentum evidenced in middle school into the high school years, students must identify with a given STEM career. This is accomplished easily with teachers instructing about careers and post-graduation options throughout the middle school years (Kier et al.).

Dooley et al. (2017) stated student retention along the STEM pathway is directly correlated with math and science grades. They indicated that factors such as gender, socioeconomic status, and immigration status play secondary roles. Although the research was conducted on Canadian high schools, it is important to note that Dooley et al. determined two key findings in their research. First, the biggest predictor of students not preparing for STEM education in high school was enrollment in advanced math and science classes. The second predictor was students' reported grades in math and science. The summation of nonacademic factors such as gender, family income, and race played a secondary role (Dooley et al.). Dooley et al. concluded that individual academic performance is the biggest predictor of retention along the STEM pathway and into STEM careers.

In 2014, the U.S. Census Bureau reported 74% of college graduates in STEM fields were not employed in a STEM field (U.S. Census Bureau, 2014). In 2012, the American Committee Survey reported engineering, computer science, math, and statistics were the largest group of graduates employed in a STEM field with approximately half working in a STEM occupation. College science and social science majors had the fewest number of graduates employed in STEM occupations with 26% majoring in physical science, 15% in biological science, agricultural, or environmental science, 10% in psychology, and 7% in other social science degrees.

Chapter Summary

This chapter provided a review of the literature defining STEM education, particularly integrated STEM education and the connection to PBL initiatives. Although a common definition of STEM education exists among researchers, there is ambiguity in the shared definition of integrated STEM education and implementation in the middle school setting. This chapter also reviewed the history of STEM education in the United States, as well as local considerations in the post steel-producing states of Ohio, Pennsylvania, and West Virginia with a focus on funding and implications for educational leaders. The historical impact of STEM programming on student achievement, particularly among underrepresented groups, such as women and minorities was discussed. Curriculum and standards encompassing current STEM education were discussed with the two main dichotomies of STEM implementation: isolation versus integration and "Some STEM for All" and "All STEM for Some" explained. The need for critical thinkers and technological literacy among the future workforce has facilitated increases in STEM education funding making this research of determining the impact of middle school STEM programming on student performance important.

The goal of this study is to determine the impact of STEM programming, particularly at the middle school level, on students' achievement to determine the effectiveness of both PLTW and PBL in relation to STEM programming.

Citation

Chine, D. R. (2022). The Literature Review on STEM Education. In J. Johnson & A. Kaban (Eds.), *A Pathway to Success? A Longitudinal Study Using Hierarchical Linear Modeling of Student and School Effects on Academic Achievement in a Middle School STEM Program* (pp. 20–50). ISTES Organization.

CHAPTER 3: MEASURING STUDENT AND SCHOOL EFFECTS ON ACADEMIC ACHIEVEMENT IN A STEM PROGRAM

"If I had an hour to solve a problem and my life depended on it, I would use the first fifty-five minutes determining the proper questions to ask."

Albert Einstein (date unknown)

Little research exists on the academic impact of STEM programming on middle school students, particularly students participating in integrated STEM education programs. In addition, there is ambiguity in defining integrated STEM education among educators and researchers. The purpose of this investigation is to define integrated STEM education within the context of middle school and determine the impact STEM programming has on student academic achievement compared to their grade level peers participating in the general education setting. This longitudinal case study analyzed student performance on OST over the course of seven years commencing in the 2012-2013 school year and ending the 2018-2019 school year.

This chapter provides an understanding of the methodology used to examine the research questions. First, the research question and objectives of the study are defined. Second, the research design and description of the quantitative research variables are described. Then, an explanation of the setting, sample participants, and staff are discussed with details of each component reviewed to provide an overview of the contextual factors in the study. Next, a description of the STEM program curriculum and details of implementation are discussed chronicling the PLTW curriculum utilized and other STEM-related projects and activities encompassing the middle school STEM program researched in this study. The following additional project-based learning programs and activities are described: annual weather balloon launch, Soap Box Derby racing and competition, and the annual STEM Showcase.

Finally, the measures of student academic achievement and performance are described with methods of data collection explained.

Research Question

The research question addressed in this study is to determine the impact of middle school integrated STEM programming on student performance and achievement. Currently, little research has been conducted on the impact of STEM programming and instruction on student academic performance, particularly performance and achievement. The primary research question to be addressed in this research is as follows:

Does middle school integrated STEM programming positively affect student achievement?

Additional research questions related to the primary questions include:

Research Question 1

Do students participating in an integrated middle school STEM program demonstrate differences in academic achievement in ELA, math, and science compared to students participating in a traditional general education setting?

Research Question 2

Do students participating in the integrated middle school STEM program demonstrate differences in achievement due to the interaction effect of gender, race, socioeconomic status, or attendance between the STEM program students and general education students?

Objectives of the Study

The main objectives of this study are as follows:

1. Define and explain middle school STEM integrated programming.
2. Determine the interaction effects of demographic factors, such as student race, gender, socioeconomic status, and student attendance rates on student achievement for students participating in a middle school integrated STEM program compared to students participating in the general education setting. To determine interaction effects of demographic factors, such as student race, gender, socioeconomic status, and student attendance rates on student achievement for students participating in a

middle school integrated STEM program compared to students not participating in the STEM program.

3. Determine the effect of middle school STEM integrated programming on student achievement. To test student achievement using OST in ELA, mathematics, and science for those that participated in middle school STEM programming compared to students achievement in the general education setting.

The key hypothesis of this study is:

H_o: The STEM Program will result in either no change or negative effects on student academic achievement which will be tested against the alternative:

H_a: The STEM Program will have positive effects on student academic achievement.

Research Design

A quantitative research approach was used to determine the impact of a middle school STEM program on student academic performance and achievement. A longitudinal case study was utilized to determine student performance over the course of seven years in a middle school STEM program. The middle school integrated STEM program researched in this study has many contextual factors within the environment which change over the course of many years making longitudinal case study research the preferred method for this investigation. Case study research is important as case studies allow for a more in-depth level of research accounting for the multi-faceted and complex variables that account in real-life situations (Crowe et al., 2011). This methodology will explain the various contextual factors that impacted the research of this longitudinal case study.

Quantitative Research Variables

There were several quantitative research variables in the study anticipated to display varying differences among student performance and achievement as reported on OST. The main research variable was student participation in an integrated middle school STEM program. Another quantitative variable was grade level from sixth to eighth grade. In addition, student subgroups, such as socioeconomic status determined by students who receive free and reduced lunch, student race, and minority status were determined and included in the study. Students with disabilities, migrants, and English language (EL) learners were not part of the study due to the small number of students in those categories being statistically insignificant. Gender differences were also reviewed to determine if there was a significant discrepancy in performance and achievement between male and female students. This longitudinal study analyzed student state assessment data from historically underrepresented populations, such as minorities, young women, and economically disadvantaged students participating in this STEM program to determine relative achievement gaps and to determine the interaction effects of demographic student factors and the school factors, such as STEM program participation on academic achievement. The purpose of this study was to determine if the STEM program has a positive effect on student performance and achievement indicating it is indeed a pathway to success.

Context and Participants

The context described in the study was the setting, environment, and details of the setting that made the research case study interesting and important. The participants were the students and teachers in the research study who participated in implementing the integrated STEM program curriculum and instruction.

Setting

The setting for the research investigation was a mid-size urban district located in northeastern Ohio. During the research investigation the district was largest in student enrollment compared to any other school district in the county with 4,437 students enrolled in grades kindergarten through 12th grade (ODE, 2019). The district comprises four buildings servicing students at the following grade levels: elementary (kindergarten through second grade, intermediate (third through fifth grade), middle (sixth through eighth grade), and high (ninth through 12th grade). Both the percent of students in the district economically disadvantaged and the minority enrollment have remained steady over the seven years of this study. In the beginning of the 2012-2013 academic year, the percent of students deemed economically disadvantaged, as defined by the number of students receiving a free or reduced lunch, was 51%. The racial composition of the district was 81% White (non-Hispanic), 10% Black (non-Hispanic), 3% Multiracial, 3% Hispanic, and less than 1% Asian or Pacific Islander. By 2019, the number of students identified as economically disadvantaged had remained steady at 51%, with a student enrollment distribution similar to the beginning of the study of 75%

White (non-Hispanic), 13% Black (non-Hispanic), 6% Multiracial, 6% Hispanic, and less than 1% Asian or Pacific Islander (ODE, 2019).

The school district of interest in this research study is known for being not only the largest district in the county but also one of the most progressive. In this capacity, the district offers many alternative educational programs for students. Along with a STEM program which launched in 2012, the district also began an online alternative educational option for students specializing in online education by providing a blended learning environment and distance education for students in grades kindergarten through 12th grade. Another alternative educational program, the HOPE Academy, "Helping Others Pursue Excellence", was created to service at-risk students who had a history of poor grades, truancy, disruptive behavior, or other behaviors which have led to temporary or permanent withdrawal from school. Both of these alternative programs offer a blended learning model for providing educational services to students.

The demographics of the middle school in the study are similar to the demographics of the district. According to the 2018-2019 local report card, the middle school had 1,061 students enrolled with the following demographic breakdown by subgroup displayed in Table 1.

Table 1. Middle School Student Demographics (n = 1,061 students)

Demographics	Enrollment #	Percentage %
Am. Indian/ Alaskan Native	NC	NC
Asian or Pacific Islander	NC	NC
Black, Non-Hispanic	136	12.8%
Hispanic	66	6.2%
Multiracial	64	6%
White, Non-Hispanic	784	73.9%
Students with Disabilities	191	18%
Economic Disadvantage	557	52.5%
English Learner	NC	NC
Migrant	NC	NC

Note. The data were compiled by the ODE (2019).

Sample Participants

The middle school of interest in the study was the first school in the county to launch a self-contained and integrated STEM program commencing the 2012-2013 school year with 25 seventh-grade students the first year and an addition of an eighth grade class the subsequent year. The population studied in this research includes all students in grades six through eight from the 2012-2013 school year until the 2018-2019 school year spanning seven years. The 2019-2020 school year was omitted from the research because there was no state assessment data due to the suspension of testing from the coronavirus school closure. Therefore, the longitudinal data are from participants at the middle school in both the general education classroom and STEM Program over the course of seven years. Student were self-selected for participation in the STEM program with interested students applying for participation. In the 2018-2019 school year, the sixth grade was added to the program with 26 students. Table 2 shows the STEM program student enrollment by grade level for each school year disaggregated by gender. The disaggregation by gender is displayed to show the number of male and female students in each grade level of the STEM program for each school year.

Table 2. STEM Program Student Enrollment by Grade Level for Each School Year Disaggregated by Gender

School Year	Grade Level	Total Students	Male	Female
2012-2013	7th	25	18	7
2013-2014	7th	25	18	7
	8th	25	18	7
2014-2015	7th	25	17	8
	8th	25	18	7
2015-2016	7th	25	15	10
	8th	25	18	7
2016-2017	7th	26	16	10
	8th	26	13	13
2017-2018	7th	27	14	13

School Year	Grade Level	Total Students	Male	Female
	8th	25	14	10
2018-2019	6th	26	19	7
	7th	26	12	14
	8th	28	16	12

Note. No data were collected for the 2019-2020 school year.

Staff

The staff at the middle school in the study were all licensed teachers through the ODE for their prospective grade level. According to the 2018-2019 school year, there were 56 general education, 14 special education, two fine arts, two music, three physical education, and three technology/STEM teachers. Among the entire staff, 100% hold at least a bachelor's degree and 81.6% hold at least a master's degree (ODE, 2019). Content teachers in grades six through eight, in the traditional general education setting, instruct in one of the following content areas: mathematics, ELA, social studies, and science. Beginning in the 2013-2014 school year, all students participating in the general education setting received two elective courses each nine weeks. The elective course offerings for both sixth and seventh grades included art, physical education, technology, and a STEM module. Students also had the options of participation in band or choir for the school year making it their second elective course. For the 2013-2014 school year, the sixth-grade PLTW STEM module taught was Design & Modeling for sixth grade and Medical Detectives for seventh grade, respectively. For the 2014-2015 school year through the 2018-2019 school year, sixth grade students received instruction in Design & Modeling and seventh grade received instruction in Energy & the Environment. No PLTW STEM modules were offered to general education students for the 2012-2013 school year. Eighth grade students received a semester of art and a semester of technology with the technology class counting as one quarter credit of high school technology credits required for high school graduation. Therefore, eighth grade students did not receive PLTW modules in their elective coursework.

STEM Program Implementation

The middle school that was the focus in this study offered STEM programming to traditional students using PLTW curriculum taught in isolation. Students in sixth grade received nine weeks of instruction in Design & Modeling and seventh grade students received nine weeks of Energy and the Environment from technology/STEM teachers. Students participating in the STEM Program received full integration of STEM programming, receiving several PLTW modules offered in nine weeks courses depending upon grade level. These PLTW modules were integrated into core content courses and taught as a full STEM integration model. All sixth and seventh grade students participating in the middle school STEM program received the PLTW Gateway curriculum modules shown in Table 3. This curriculum was taught by two core content teachers each instructing both Math and Science and Social Studies/Language Arts, respectively.

Table 3. STEM Program Modules Taught by School Year and Grade Level

School Year	Grade Level	PLTW Gateway Modules Taught
2012-2013	7th	Design & Modeling Energy & the Environment Automation & Robotics
2013-2014	7th	Design & Modeling Energy & the Environment Automation & Robotics Part 1
	8th	Automation & Robotics Part 2 Magic of Electrons Flight & Space
2014-2015 through 2017-2018	7th	Design & Modeling Energy & the Environment Automation & Robotics Part 1
	8th	Automation & Robotics Part 2 Magic of Electrons

School Year	Grade Level	PLTW Gateway Modules Taught
		Flight & Space
		Green Architecture
2018-2019	6th	Design & Modeling
		Medical Detectives
		Automation & Robotics Part 1
	7th	Design & Modeling
		Medical Detectives
		Automation & Robotics Part 1
	8th	Automation & Robotics Part 2
		Magic of Electrons
		Flight & Space
		Green Architecture
		Computer Apps for Inventors & Creators

Note. Automation & Robotics was split into two courses, Part 1 and 2, due to the extensiveness of the course.

The integrated STEM Program PLTW Gateway modules illustrated in Table 3 show the modules taught. These nine-week modules were taught in conjunction with the content area courses of science, mathematics, ELA, and social studies in an integrated learning environment using PBL. In addition to the described PLTW modules, students participating in the STEM program engaged in two comprehensive and interdisciplinary projects annually: the building and racing of Soap Box Derby cars and the launching and retrieving of a weather balloon.

Soap Box Derby

The All-American Soap Box Derby (AASBD) is a gravity-racing program for youths between the ages of seven and 20 years old. The AASBD is part of the International Soap Box Derby which was founded in 1934 in Akron, Ohio. The AASBD has their own educational racing program designed for schools called the Gravity Racing Challenge (GRC) STEM Team Competition. Every year students participating in the STEM program compete in the GRC STEM Team Competition by building GRC cars and racing in May at Derby Downs in Akron, Ohio. Seventh grade students build three stock cars (designed for children between seven and 13 years old) and eighth grade students build three superstock cars (designed for students between nine and 18 years old), respectively (Soap Box Derby, 2020). Along with the instructional component involved with building the Soap Box Derby cars there was an AASBD sponsored and approved curriculum. The curriculum for the GRC STEM Team Competition coined the "Masters of Gravity" followed the learning cycle proposed by Bybee (1997) focusing on the five pillars of the learning cycle; engagement, exploration, explanation, elaboration, and evaluation. The curriculum consisted of eight lessons, called programs, of varying lengths designed to encompass all subjects of science, technology, engineering, and mathematics. The programs were taught in conjunction while building the cars and commenced in the following order: Collection and Analysis, Ratio and Proportion, Geometry, Simple Machines, Gravity, Energy, Friction, and Speed. The entire "Masters of Gravity" curriculum took approximately two months to complete. The program begins in March and resolves with the GRC STEM Team Competition races in May of each school year (Masters of Gravity, n.d). In addition to the building of the Soap Box Derby cars and implementing the curriculum programs ,students participated in the optional competitions associated with the GRC STEM Team Competition of the photography contest, infomercial creation, and press release design. The participation of the STEM program students in the GRC STEM Team Competition was funded by private sponsors and local donations.

Weather Balloon Launch

Every year the eighth grade STEM program students launch a weather balloon as a supplemental PBL project complementing the PLTW Flight and Space module. Students were responsible for researching and organizing the weather balloon launch which consists of a 1200 gram balloon filled with helium and carrying a payload containing two GoPro cameras and an onboard flight computer with sensors to collect data such as temperature, pressure, and humidity. A select group of eighth-grade STEM students tracked and chased the balloon until it was retrieved and the data were then analyzed in the classroom using concepts learned in the PLTW Flight and Space module. This is an example of a PBL project encompassing Bybee's (1997) five aspects of the learning cycle used in many STEM programs and activities today.

Instrumentation

Student achievement was measured using OST data as instruments and reported by the ODE. Student demographic data were collected from the Education Management Information System (EMIS) database of the school district which is also reported to the ODE. Student demographic information consisted of student race, defined as: American Indian or Alaskan Native, Asian or Pacific Islander, Multiracial, Hispanic, Black (non-Hispanic), and White (non-Hispanic). Both race and socioeconomic status were self-reported by parents and guardians to the school district. Race was self-reported by parents and guardians with no required documentation. Socioeconomic status was derived from free- and reduced-lunch status reported by family group W-2 forms and was considered a valid metric for assessment of socioeconomic status. This study did not examine ELLs and migrants due to the low number of students in each population studied.

The student measure of academic achievement was determined using annual OST scores taken each spring by students in grades three through eight for all students in the state of Ohio. Testing is mandatory in grades three and above with particular tests by subject required at the high school level with an appropriate score required for graduation. Students take English Language Arts (ELA) and mathematics OST every year. Science testing occurs for students in their fifth- and eighth-grade year.

OST scores, grades, and other indicators of academic success were retrieved and reported. OST scores were obtained from various vendors in different years. These included: The Ohio Achievement Assessments (OAA), Partnership for Assessment of Readiness for College and Careers (PARCC), and the American Institute of Research (AIR). Table 4 displays the OST test name disaggregated by school year and content. There was suspension of state testing for the 2019-2020 school year due to the coronavirus crisis which caused school closure and suspended state testing. Therefore, no student test data were collected for the 2019-2020 academic school year.

Table 4. Ohio State Test Name by School Year and Test Subject

School Year	Test Subjects	Test Name
2012-2013 through 2013-2014	English Language Arts	OAA
	Mathematics	
	Science	
2014-2015	English Language Arts	PARCC
	Mathematics	
	Science	AIR
2015-2016 through 2018-2019	English Language Arts	AIR
	Mathematics	
	Science	

Scale and Scoring System of Instrument

Over the course of seven years of this study, the ODE utilized three different testing vendors for the administration of state testing: OAA, PARCC, and AIR. These state assessments were norm-referenced and mandatory for all students attending schools in the state of Ohio and approved as a method of providing standardized education by the NCLB Act of 2001. OAA was administered for the 2012-2013 and 2013-2014 school years for both reading and math.

The Rasch model (a single parameter logistic model) was used for the conversion of raw scores to scaled scores. This accounts for the levels of difficulty and abilities of students taking the assessment. The Rasch model determines estimates of the level of difficulty of test questions and the ability of each student on a linear scale to determine the probability of getting each question correct and adjusted scores accordingly. Table 5 reveals the scaled scores for each performance level on the OAA.

The five performance levels in increasing order are as follows: limited, basic, proficiency, accelerated, and advanced. For the purposes of data reporting, performance levels are numbered from one to five and are coded as followed: limited = 1, basic = 2, proficient = 3, accelerated = 4, and advanced =5. All assessments used the same coding system for each performance level. Proficiency or passage was determined to be a scaled score of 400. It is important to note that scaled scores are not comparable between grade levels and test subjects. Reliability of all OAA assessments across subjects and test years ranged from 0.87-0.90 using Cronbach's alpha and the standard error of measurement (SEM) ranged from 10.24-13.03, respectively (ODE, 2014).

Table 5. 2012-2013 and 2013-2014 Cut Scaled Score Points for Basic, Proficient, Accelerated, and Advanced Standards, OAA Administration

Grade	Subject	Limited	Basic	Proficient	Accelerated	Advanced
7	Reading	<379	379	400	432	452
	Math	<378	378	400	436	458
8	Reading	<378	378	400	428	451
	Math	<379	379	400	432	459
	Science	<365	365	400	427	445

In the 2014-2015 school year, the ODE used PARCC as the mandated Ohio state assessment. Table 6 illustrates the scaled scores for each performance level with proficiency determined with a scaled score of 725. Similar to OAA, scaled scores are not comparable between grade levels and test subjects (ODE, 2015).

Table 6. 2014-2015 Scale Score Ranges for All Subjects and Performance Levels, PARCC Administration

Grade	Subject	Limited	Basic	Proficient	Accelerated	Advanced
7	ELA	650-699	700-724	725-749	750-784	785-850
	Math	650-699	700-724	725-749	750-785	786-850
8	ELA	650-699	700-724	725-749	750-793	794-850
	Math	650-699	700-724	725-749	750-800	801-850

Beginning in the 2015-2016 school year and continuing through the 2018-2019 the ODE administered the AIR assessments. Table 7 illustrates the cut scaled scores for each performance level similar to the OAA and PARCC assessments. Passing is defined as achieving proficiency level or getting at least a 700 scaled score on the assessment. Similar to the state assessments mandated before AIR, scaled scores are not comparable between grade levels and test subjects. In addition, students receiving a DNA or INV in data reports either “did not attempt” or the data was “invalidated”, respectively (ODE, 2019).

Table 7. 2015-2016 through 2018-2019 Scale Score Ranges, AIR Administration

Grade	Subject	Limited	Basic	Proficient	Accelerated	Advanced
6	ELA	555-667	668-699	700-724	725-750	751-851
	Math	616-681	682-699	700-724	725-743	744-790
7	ELA	568-669	670-699	700-724	725-748	749-833
	Math	605-683	684-699	700-724	725-754	755-806
8	ELA	586-681	682-699	700-724	725-743	744-805
	Math	633-689	690-699	700-724	725-743	744-774
	Science	575-673	674-699	700-724	725-765	766-868

Reliability and Validity of the Instrument

The reliability and validity of Ohio state assessment data are reported annually through the ODE. Reliability of all OAA assessments across subjects and test years ranged from 0.87-0.90 using Cronbach’s alpha and the standard error of measurement (SEM) ranged from 10.24-13.03, respectively (ODE, 2014). Reliability of AIR assessments across reading, math, and science tests for the 2015-2016 through the 2018-2019 school years ranged from 0.90-0.94 using Cronbach’s alpha and the SEM ranged from 9.81-15.49 (ODE, 2020). Reliability measures from the one year (2014-2015) administration of the PARCC assessment could not be found, perhaps because the assessment was only given for one year. The reported

Cronbach's alpha measures for calculating internal consistency are all well above 0.70 indicating all administered assessments have strong reliability.

The validity of using OST scores as an instrument for determining achievement is commonly used by researchers and is considered one of the stronger methods of defining achievement. State assessments are norm-referenced and standardized to ensure alignment with Ohio's Learning Standards for each grade level and subject. The process of creating test questions and scoring parameters was completed by assessment committees in several areas: content advisory, range finding/ rubric validation, fairness/sensitivity, standard setting, and alignment study committees (ODE, 2020). Each committee is made up of licensed Ohio educators and higher education members that specialize in these specific areas. In addition, many different stakeholders were consulted to ensure Ohio state assessments have content validity and are accurately measuring students' knowledge based on the standards of each tested subject and grade level (ODE, 2020).

Data Collection Procedure

Permission for this research project was granted through the school district's superintendent in accordance with the local school district policy, and also through the Youngstown State University (YSU) office of Institutional Research. Institutional Review Board (IRB) approval was obtained under exempt status (see Appendix B). After IRB approval, existing and de-identifying OST data were sent electronically via email. All individual student demographic and OST data were retrieved from the Ohio Department of Education Secure Data Center online using the appropriate permissions and removing student names and student state identification (SSID) numbers prior to being sent electronically to the researcher. The electronic data encompassed individual student demographic and OST data from school year 2010-2011 through 2018-2019 taken over the course of nine years. Students were linked with randomly assigned identification numbers with data organized into spreadsheet files compatible with IBM SPSS for data analysis.

Data Analysis Methods

The method of data analysis used in the study was multilevel modeling. Multilevel modeling is used in many fields of study particularly in education, social work, health, business sectors, and the social sciences (Woltman et al., 2012). This type of modeling is known by several names, such as hierarchical linear-, mixed level-, mixed effects-, random effects-, random coefficient (regressions), and (complex) covariance components- modeling (Raudenbush & Bryk, 2002). Multilevel modeling and HLM are complex forms of ordinary least squares (OLS) regression and are used when predictor variables are at different hierarchical levels to determine the variance within the outcome variables. HLM is primarily used for creating statistical models of variables that depend on more than one level, or nested data. HLM simultaneously determines relationships within and among hierarchical levels within data sets thereby making it an effective method of calculating variance among variables at varying levels than other statistical analysis techniques. HLM is becoming an increasingly popular method of advanced statistical analysis due to advancement in statistical theory and statistical modeling programs (Woltman et al.).

The goal of this study was to determine the academic achievement of individual students as a function of different levels within nested data sets. This aligns with the main objective of this study to determine the effect of middle school STEM integrated programming on student achievement using OST scores as a measure of achievement. The related research question contains two hierarchical levels: what grade level and classroom level, and student-related factors affect student achievement? Table 8 displays the three hierarchical levels defining their category and factors, also known as variables at each particular level. The variable name used during SPSS and HLM analysis is listed also. HLM was used to analyze OST data for students in grades six through eight to determine the effects of student achievement, the outcome variable, as a function of varying hierarchical levels.

The higher level, (level-2) is the school-related variables pertaining to grade level, which are grades six, seven, and eight depending on school year. The other level-2, school-related variables are whether students participated in a STEM program or a general educational setting. Level-1 variables are located within level-2 groups. The level-1, student-related variables in this research study consist of OST scores, gender, race, and socioeconomic status. These level-1 variables are located within groups inside Level-2 and together are influenced by level-2 variables. To summarize, students (level-1) are encapsulated in classrooms (level-2) that are nested inside of schools (see Table 8). The OST score, which is the outcome variable, is assessed at level-1. In HLM, the targeted variable of interest and the outcome variable are found at the lowest hierarchical level (Woltman et al., 2012).

Table 8. Factors at Each Hierarchical Level that Affect Students' Achievement with Variables' Names

Hierarchical Level	Category	Variables	Variable Name
Level-2	School Level	Participation in a STEM program	STEM
		Participation in the general education setting	
		Grade 6	GRADE6
		Grade 7	GRADE7
		Grade 8	GRADE8
Level-1	Student Level	OST scores	OST
		Gender	GENDER
		Race	RACE
		Socioeconomic Status	SES
		Attendance	ATTEND

HLM can accommodate more than one outcome variable in one analysis. In addition, the outcome variables can be discrete or continuous (Raudenbush & Bryk, 2002). For the purposes of this research study, the primary outcome variable was OST scores, however, the other level-1 variables consisting of gender, race, socioeconomic status, and student attendance rate were analyzed using HLM to determine variance among variables. The coding of discrete variables were given the following number system: GENDER; female= 1 and male=0, RACE= Am. Indian/ Alaskan Native=1, Asian=2, Black=3, Hispanic=4, Multiracial=5, Puerto Rican=6, White (Non-Hispanic)=7 and SES; yes=1 and no=0. Student attendance rate was coded as percent attendance as a decimal rate. For example, a student present every day of school, 186 days out of 186 school days was coded as ATTEND=1. A student attending exactly half of the days was coded as ATTEND=0.5, and a student enrolled who never attended was coded as ATTEND=zero. This ensured student attendance did not skew data for those coming a portion of the school year. This also ensured students with poor attendance were accounted for correctly within the data distribution.

The use of HLM is the preferred method of analyzing multilevel datasets as it accounts for the communal variance fundamental to hierarchical datasets. Basic linear regression methods, disaggregation, and aggregation, which did not consider hierarchical data and their shared variances, were used by researchers prior to the use of HLM. Although both of these outdated methods made analyzing hierarchical data possible they created other problems. These included the wrong variances assigned between variables, data dependencies, and an increased probability of a Type I error (Woltman et al., 2012).

Disaggregation of data ignores the differences in hierarchical structure among the data treating all relationships between variables at hierarchical level-1, or the individual level. This method of data analysis disregards between-group differences in variances. Table 9 shows a hypothetical dataset if disaggregation was to be used in this study. The following dummy variables are defined as: gender; 1=female and 0=male, STEM Program Participation; 1=yes and 0=no. The upper level variables of level-2 (school) are treated as level-1 (student).

All students in a STEM program would be attached to similar classroom-related OST scores, and all participants in similar grade levels would be attached to similar grade-level OST scores, thus bringing all upper level hierarchical variables down to level-1. When this occurs, data dependencies are not corrected, statistical methods are established only from the sample size at level-1, and the probability of measuring variances falsely increases. In addition, the independence assumption required for simple linear regression is violated. All of these factors and the disregard for variance differences between groups using the disaggregation method is the reason HLM is the preferred method of statistical data analysis for this research study (Woltman et al., 2012).

The other method used to analyze multilevel data prior to the widespread use of HLM is aggregation. Aggregation is a simple linear regression method that disregards lower level individual differences, instead of ignoring upper level differences, such as with disaggregation. Level-1 variables are treated at a higher level making variability among individuals disappear and all students are treated as homogenous entities (Gill, 2003; Woltman et al., 2012).

Table 9. Sample Dataset Using the Disaggregation Method, with Level-2 and Level-3 Variables Excluded from the Data

Student ID (Level-1)	School ID (Level-2)	Grade ID (Level-3)	OST Score (Level-1)	STEM Program Participation (Level-2)	Gender (Level-1)
1	1	6	724	1	1
2	1	6	734	1	0
3	1	6	701	0	1
4	1	7	688	1	0
5	1	7	723	1	1
6	2	7	714	0	0
7	2	7	678	0	0
8	2	8	704	1	0
9	2	8	697	1	1
10	2	8	699	0	1

Table 10 shows a sample dataset of the aggregation method used in this study with all level-1 variables treated as higher hierarchical levels. The aggregation method makes the mean classroom or grade OST score become the targeted outcome variable of focus, rather than individual student achievement indicative by OST score. Raudenbush and Byrk (1992) reported approximately 80%-90% of deviation among individual differences is lost when the aggregation method is used. HLM is often chosen instead of aggregation in reference to hierarchical information due to its successful separation of group and individual effects on the variable of interest (Woltman et al., 2012).

The hypothesis in this research study is students participating in an integrated middle school STEM program will demonstrate more academic achievement in math and science than students participating in a traditional general education setting. The null hypothesis is the absence of any effect. In addition, the determination of any effect of other level-1 predictor variables described earlier: gender, student race, socioeconomic status, and attendance will be conducted using HLM.

Table 10. Sample Dataset Using the Aggregation Method, with Level-1 Variables Excluded from the Data

Classroom ID (Level-2)	Classroom OST Score (Level-2)	STEM Participation (Level-2)
1	724	1
2	734	0
3	701	1
4	688	0
5	723	1

In HLM, the mathematical theory and equations help conceptualize the concept of lower-level units representing individual students and higher-level units representing classrooms or whole grade levels. The complexity of HLM calculations increases exponentially with every increase in hierarchical level (Raudenbush & Bryk, 2002, Woltman et al., 2012). Therefore, the mathematical equations were more simply described based on a two-level hierarchical model. Of note, a two-level model was utilized in this research study instead of a three-level model due to these reasons. The simple linear regression created for each individual student *i:*

$$Y_{ij} = \beta_{0j} + \beta_{1j} X_{ij} + r_{ij} \quad (1)$$

where:

Y_{ij} = dependent variable measured for the *i*th level-1 unit nested within the *j*th level-2 unit,

X_{ij} = value on the level-1 predictor,

β_{0j} = intercept for the *j*th level-2 unit,

β_{1j} = regression coefficient associated with the X_{ij} for the *j*th level-2 unit, and

r_{ij} = random error associated with the *i*th level-1 unit nested within the *j*th level-2 unit.

(Woltman et al., 2012)

In context to the research problem the variables can be redefined as follows:

Y_{ij} = OST scores for student *i* in classroom *j*

X_{ij} = Participation in a STEM Program for student *i* in classroom *j*

β_{0j} = OST scores for student *i* in classroom *j* who did not participate in a STEM program

β_{1j} = regression coefficient associated with participation in a STEM program for the *j* classroom

r_{ij} = random error associated with student *i*

One important assumption of HLM is that any level-1 errors (r_{ij}) are normally distributed with a mean of zero and a variance equal to σ^2 (Woltman et al., 2012). For a level-2 model, the level-1 regression coefficients ($\beta_{0j} + \beta_{1j}$) are used as outcome variables and are connected to the level-2 predictors. The mathematical equation at level-2 becomes increasingly complex and supports the use of computerized statistical modeling programs, such as IBM SPSS software.

In a level-2 model, the level-1 regression coefficients of β_{0j}, OST scores for student *i* in classroom *j* who did not participate in a STEM program, and β_{1j}, the regressions coefficient associated with participation in a STEM program for the *j* classroom are used as outcome variables and are connected to each of the level-2 (classroom) predictors. For this reason, level-2 models are also called between-unit models as they describe the variability among many groups (Gill, 2003; Woltman et al., 2012). Equations and 2 and 3 conceptualize the case of a single level-2 predictor:

$$\beta_{0j} = \gamma_{00} + \gamma_{01}G_j + U_{0j} \tag{2}$$

$$\beta_{1j} = \gamma_{10} + \gamma_{11}G_j + U_{1j} \tag{3}$$

where:

β_{0j} = intercept of the *j*th level-2 unit;

β_{1j} = slope for the *j*th level-2 unit;

G_j = value on the level-2 predictor;

γ_{00} = overall mean intercept adjusted for *G*;

γ_{01} = regression coefficient associated with *G* relative to level-1 intercept;

γ_{11} = regression coefficient associated with *G* relative to level-1 slope;

U_{0j} = random effects of the *j*th level-2 unit adjusted for *G* on the intercept;

U_{1j} = random effects of the *j*th level-2 unit adjusted for *G* on the slope.

In context to the research problem, the variables can be redefined as follows when considering any level-1 predictor variable, in this example socioeconomic status:

β_{0j} = intercept of the *j*th classroom;

β_{1j} = slope for the *j*th classroom;

G_j = participation in a STEM or general education program;

γ_{00} = overall mean intercept adjusted for SES;

γ_{10} = overall mean intercept adjusted for SES;

γ_{01} = regression coefficient associated with SES relative to level-2 intercept;

γ_{11} = regression coefficient associated with SES relative to level-2 slope;

U_{0j} = random effects of the *j*th classroom adjusted for SES on the intercept;

U_{1j} = random effects of the *j*th classroom adjusted for SES on the slope.

The example given above illustrates how to determine the effect of variances in between groups among hierarchical data. Socioeconomic status (SES) is one of the level-1 (student) predictors that was analyzed using HLM to determine its effect on students OST scores as a dependent function of a level-2 (classroom) predictor of either STEM or general education programming. It is important to note that the level-2 (classroom) model brings two new terms (U_{0j} and U_{1j}) that Woltamn et al. (2012) identified as both unique to HLM. This allows for the model to determine an estimation of error that normal linear regression cannot determine. The covariance between β_{0j}, the intercept of the *j*th classroom, and β_{1j}, the slope for the *j*th classroom is equal to the covariance between U_{0j}, the random effects of the *j*th classroom adjusted for socioeconomic status and U_{1j}, the random effects of the *j*th classroom adjusted for socioeconomic status on the slope. The assumptions of the level-2 (classroom) models are as follows (Raudenbush & Bryk, 2002, Woltman et al., 2012):

$$E(U_{0j}) = 0;\ E(U_{1j}) = 0$$

$$E(\beta_{0j}) = \gamma_{00}\ ;\ E(\beta_{1j}) = \gamma_{01} \qquad (4)$$

$$\mathrm{var}(\beta_{0j}) = \mathrm{var}\ (U_{0j}) = \tau_{00}\ ;\ var(\beta_{1j}) = var(U_{1j}) = \tau_{11}$$

$$cov(\beta_{0j}, \beta_{0j}) = cov(U_{0j}, U_{1j}) = \tau_{01}$$

$$cov(U_{0j}, r_{1j}) = cov(U_{1j}, r_{1j}) = 0$$

A combined model of equations 2 and 3 can be created to create equation 5. This combined model contains both level-1 (student) and level-2 (classroom) predictors (X_{ij} or socioeconomic status and G_{ij} or participation in a STEM or general education program) and a term going across levels (G_jX_{ij} participation in a STEM or general education program multiplied by socioeconomic status). The error is represented by $U_{1j}X_{ij} + U_{0j} + r_{ij}$. Equation 5 is called a mixed model as it contains both random and fixed effects which is unique to HLM (Woltman et al., 2012).

$$Y_{ij} = \gamma_{00} + \gamma_{10}X_{ij} + \gamma_{01}G_j + \gamma_{11}G_jX_{ij} + U_{1j}X_{ij} + U_{0j} + r_{ij} \quad (5)$$

The combined model in equation 5 is similar to a normal regressions but adds two new terms, U_{1j} and U_{0j}, which introduces an error estimation that is not a part of normal regression. Equation 5 demonstrates a dependency between level-1 (student) clustered within level-2 (classroom). In addition, U_{1j} and U_{0j}, may possess different values between level-2 units creating heterogeneous variances of the error terms.

According to Woltman et al. (2012), there are five conditions that must be met in order to use HLM appropriately and effectively. Conditions two and three must be met prior to conditions four and five. The following conditions apply to this research study:

Condition 1: There is systematic within- and between- group variance in OST scores.

Conditions 2 and 3: There is significant variance in the level-1 (student) intercept and slope.

Condition 4: The variance in the level-1 (student) intercept is predicted by participation in a STEM or general education program.

Condition 5: The variance in the level-1 (slope) is predicted by participation in a STEM or general education program.

IBM SPSS software originally stood for Statistical Package for Social Sciences but now is only known now by the acronym. This widely-used statistical analysis package was used to perform HLM statistical calculations in this research study. The IBM SPSS data software was used due to its ability for prediction among nested groups using cluster analysis of HLM.

There are several advantages to using the multilinear modeling technique called HLM. First, the ability of HLM to simultaneously determine relationships between groups makes it very efficient for determining variances among different leveled groups. Second, HLM does not violate many of the statistical assumptions necessary in using older statistical techniques such as disaggregation and aggregation. This type of multilevel modeling is more accepting of violations in observation independence, homogeneity, and sphericity. HLM has little effect on standard errors, effect size, and variances. Finally, HLM is an effective method of determining the differences in variances between nested data as discussed previously (Gill, 2003; Woltman et al., 2012).

Internal and External Validity of the Research Design

Students within this research study were situated into schools which were nested into classrooms with no manipulation of independent variables. The large sample size at level-3 (approximately 350 students) and the longitudinal nature of seven years increased the study's external validity.

Analytical Limitations

Although there are many advantages to using HLM and other multilevel, statistical modeling techniques, Dedrick et al. (2009) discussed several limitations and concerns to using HLM for data analysis that are applicable to this research study. The limitations fall into one of four categories: model development, hypothesis testing, data considerations, and estimation processing. Model development and specification issues are troublesome when determining and selecting predictor variables. The regression equations can become extremely complicated, especially when it is not feasible for predictor variables to have zero points. A second limitation related to using HLM for hypothesis testing and statistical inference occurs when sample sizes or variances parameters are small. Due to small sample size, degrees of freedom may need adjustment when there is a violation of normality. Dedrick et al. commented that there are two methods of making inferences to overcome this problem. One method is to estimate the level-1 (grade level) coefficient separately from level-2 (classroom level) using OLS, which has its own limitations. Also, the researcher can use empirical Bayes estimates, which consider all data but bias estimates. However, Bayes estimates tend to generate values more accurate to the parameter values. Dedrick et al. stated that there is, in fact, no estimation method which satisfies all conditions. Considerations of sample size and normality can assist researchers in determining which estimation method is the most appropriate for the research study (Dedrick et al.).

An additional limitation to using HLM emphasized by Woltman et al. (2012) for traditional applications of HLM, is that substantial sample sizes are necessary at each level for sufficient power. Recently, researchers have overcome this problem by increasing the number of groups instead of increasing the number of observations per group. Groups of less than 50 could yield biased approximations of standard errors at the second level (Woltman et al., 2012). For the purposes of this research design, the level-2 (grade level tests) had approximately 9 groups and level-1 (classroom level) contained approximately 3,000-4,000 students, depending on the test year.

There are a few limitations to the data collection and research design not necessarily related to the use of HLM. The study population is limited to a single institution versus data collection from other similar programs in the state. If other programs were included, the significance of the individual program teachers and instructors would be diminished. In this dataset, race was self-reported by the parent or guardian, leading to a degree of potential inaccuracy. The transition from PARCC to AIR assessments for mathematics and ELA can create reliability issues as two different assessments were used to measure student performance and achievement. Other factors seemingly unrelated to the STEM program may have effects on student performance and achievement. It is hypothesized that teacher experience and self-efficacy plays an important role in student achievement and intellectual development. Finally, migration of students in and out of the STEM program may be a threat that affects both internal validity and reliability.

Chapter Summary

The reliability and validity measures of state assessment scores are dependent upon the accuracy reported by the makers of the OAA, PARCC, and AIR assessments. Reliability measures of state assessments across all years in this study and test subjects were reported to be strong with Cronbach's alpha values greater than 0.7. SEM values were fairly low, depending on performance level scaled score values. Norm-referenced and standardized state assessments are considered the gold standard for quantifying student achievement. This is why OST scores were used in this study. Demographic data of students were self-reported by parents. The school identified gifted students and English learners. Economically disadvantaged data were determined via student participation in the free or reduced lunch program. The validity of parent-reported measures cannot be controlled.

The use of HLM for data analysis is the preferred method of analyzing multilevel datasets as it accounts for the shared variance inherent within hierarchical data. The purpose of using HLM in this study was to determine the impact of STEM programming on achievement when students are nested within level-2 (classrooms) which are clustered into level-3 (grade levels). The level-1 (student) variables of OST scores, gender, race, and socioeconomic status were used to determine the variances of in-between groups. With participation in STEM or general education programs being a predictor of the level-1(student) slope, the use of HLM was used to determine the level of moderation between STEM programming and predicting for all level-1 (student) predictors. In conclusion, the percent of variance in regard to STEM programming can be calculated as a moderator in the OST-score and demographics relationships, including but not limited to gender. The hypothesis in this research study was students participating in an integrated middle school STEM program will demonstrate more academic achievement in ELA, math, and science than students participating in a traditional general education setting when correcting for variances among other level-1 (student) demographic variables.

Citation

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CHAPTER 4: FINDINGS FOR STUDENT AND SCHOOL EFFECTS ON ACADEMIC ACHIEVEMENT IN A STEM PROGRAM

"We should not teach children the science but give them a taste for them."

Jean Jaques Rosseau (date unknown)

The goal of this study was to determine the impact of STEM programming, particularly at the middle school level, on students' achievement to determine the effectiveness of both PLTW and PBL in relation to STEM programming. Student achievement was measured by the scaled score on Ohio State Tests (OST) in math and science over the course of seven years. The proposed factors affecting student achievement were STEM participation, gender, race, socioeconomic status, and attendance. Table 11 displays the two hierarchical levels of school and student level defining their category and factors, also known as variables, at each particular level. HLM was used to analyze OST data for students in grades five through eight to determine the effect of student achievement, the outcome variable, as a function of varying hierarchical levels.

This chapter displays the variable and sample descriptions with descriptive statistics related to each research question. The descriptive statistical information for OST scores by year are displayed indicating the mean, standard deviation, minimum score, maximum score, skewness, and kurtosis for each subject, grade level, and year. The inter-correlation between variables were shown with preliminary bivariate relationships indicated by Pearson correlation coefficients. Two HLM models were created addressing the research questions. The higher level, (level-2), are the school-related variables pertaining to grade level, which are grades 6, 7, and 8th, depending on school year. The other level-2, school-related variables represent whether students participated in a STEM program or a general educational setting. Level-1 variables are located within level-2 groups. The level-1, student-related variables in this research study consist of OST scores, gender, race, and socioeconomic status. These level-1 variables are located within groups inside Level-2 and together are influenced by level-2 variables. To summarize, students (level-1) are encapsulated in classrooms (level-2) (see Table 11*)*. The OST score, which is the outcome variable, is assessed at level-1. In HLM, the targeted variable of interest and the outcome variable are found at the hierarchical level at the lowest value (Woltman et al., 2012).

Table 11. Proposed Factors at Each Hierarchical Level That Affect Students' Achievement

Hierarchical Level	Category	Variables	HLM Variable Code
Level-2	School Level	Participation in a STEM program	STEMMARK
		Participation in the general education setting	
		Assessment Type (grade and school year)	ASSMTTYP
		5^{th}- and 8^{th}- grades' science tests	GRADE
Level-1	Student Level	OST scaled score	SCALEDSC
		Gender	GENDER
		Race	RACE
		Socioeconomic Status	SES
		Attendance	ATTEND

HLM can accommodate more than one outcome variable in one analysis. HLM is often used in place of the Analysis of Covariance (ANCOVA) because HLM can analyze multilevel data without homogeneity among regression slopes necessary in ANCOVA. In addition, the outcome variables can be discrete or continuous (Raudenbush & Bryk, 2002). For the purposes of this research study, the primary outcome variable was OST scores, however, the other level-1 variables consisting of gender, race, socioeconomic status, and student attendance rate were analyzed using HLM to determine variance among variables. The coding of discrete variables provided the following number system: gender: female= 1 and male=0, race= Am. Indian/ Alaskan Native=1, Asian= 2, Black=3, Hispanic=4, Multiracial=5, Puerto Rican=6, White (Non-Hispanic)=7, and economic disadvantage; yes= 1 and no=0.

Variable and Sample Descriptions

The student level (level-1) variables and the corresponding variable label indicating the variable coding are shown in Table 12.

Table 12. Student Level (Level-1) Variables with the IBM SPSS (v. 26) Label and Variable Coding

Student Level Variables	Label	Variable Coding
Socioeconomic status	SES	Economically disadvantaged=1, Not economically disadvantaged= 0
Gender	GENDER	Female=1, male=0
Race	RACE	White (Non-Hispanic)=7, Puerto Rican= 6, Multiracial=5, Hispanic=4, Black (Non-Hispanic)=3, Asian=2, Alaskan Native/ Am. Indian=1
Attendance	ATTEND	Between or equal to 0 and 1. Coded as percent attendance at a decimal rate.
OST Score	[Year_Subject]	Ohio State Assessment scaled score for a given academic year and subject; Subject is coded as math or science; Year is 2013 through 2019; 5^{th}- grade science data 2010 through 2016

Attendance rate was coded as percent attendance at a decimal rate. This was calculated for students by taking the number of present days for the specific school year and dividing by the summation of days present, days absent (unexcused) and days absent (excused). The quotient was a decimal rate used as the ATTEND code for a given student in a specific school year. This ensures accuracy in determining intercorrelation between student attendance and achievements. Table 13 displays the school-level variables with the given IBM SPSS (V. 26) labels and codes indicating student grade levels of five, seven, and eight. Student participation in integrated STEM programming was indicated by 1 and student participation in a general education setting was shown by 0.

Table 13. School Level (Level-2) Variables with the SPSS Label and Variable Coding

School Level Variables	Label	Variable Coding
Grade	Grade	Grade 5= 5, Grade 7=7, Grade 8=8
Participation in a STEM Program	STEM	Student participation in a STEM program=1, Student participation in a general education setting and not in a STEM program=0

The student level (level-1) OST data collected for each academic year beginning in the school year 2010-2011 and concluding in 2018-2019 is displayed in Table 14 along with the grade level and test subject.

Table 14. Student Level (Level-1) OST Data Collected by Academic Year, Grade Level, and Test Subjects

Academic Year	5th grade	7th grade	8th grade
2010-2011	Science		
2011-2012	Science		
2012-2013	Science	Math	
2013-2014	Science	Math	Math Science
2014-2015	Science	Math	Math Science
2015-2016	Science	Math	Math Science
2016-2017		Math	Math Science
2017-2018		Math	Math Science
2018-2019		Math	Math Science

Notice that school year 2010-2011 and 2011-2012 OST data were collected for fifth-grade students only. The STEM program began in 2012-2013 for students in 7th grade only, however fifth-grade science OST data were collected to determine the effect on science achievement by comparing fifth-grade science scores to eighth-grade science scores after participation in two years of integrated STEM programming. Therefore, all fifth-grade OST data were used for control data for comparison upon treatment (two years of integrated

STEM programming) and comparison with eighth grade science OST data. Thus, fifth-grade science OST data only needed to be collected commencing in the 2010-2011 school year and concluding in the 2015-2016 school year.

Data Screening and Assumptions

All necessary data were received in two Excel spreadsheet files. The first file contained all raw data necessary for the study with each individual participant's unique student number and OST score indicated as a row in the spreadsheet. All other data were located in a column. The second file listed the student numbers for STEM participants. There were several necessary modifications made to the files in order to create one spreadsheet compatible for analysis via SPSS.

First, the spreadsheet was reorganized with each unique student number as a row and individual OST scores, demographic information, and attendance for each year as a column. OST scaled score was used in the study and the raw scores and number of test attempts were removed from the data spreadsheet. Second, raw attendance information was given in three columns; number of days present, number of unexcused days absent, and number of excused days absent. To determine the attendance rate as a decimal, a new column was created adding excused absences, unexcused absences, and days present to get the total. Then the number of days present was divided by the total number of days. This equation proved accurate given each school year contained a different number of days in a school year. In addition, the equation corrected for students attending the school or district only part of the school year. Finally, the student numbers of STEM participants were merged into the spreadsheet containing all data as a new column indicating STEM designation (STEM=1) and all other participants a zero.

Missing Data & Outliers

There was a substantial number of participants missing attendance information for any given year. In SPSS, those cells were identified as missing in SPSS using ATTEND=9999 and coding "9999" as a missing data point. In addition, only students with OST scores were included in the initial data spreadsheet. However, a few students had an OST score for math in a given year but no score indicated for ELA and vice versa. Students with missing scores were removed from the study. There were no outliers indicated in the data.

Descriptive Statistics Related to Each Research Question

Descriptive statistics for both student and school-level variables are displayed and explained below as they are related to each research question.

Research Question 1:

Do students participating in an integrated middle school STEM program demonstrate differences in academic achievement in math and science compared to students participating in a traditional general education setting?

Descriptive statistics for student OST scores are segregated by STEM participation in Table 15 through Table 23 beginning in school year 2010-2011 with fifth-grade science OST and concluding with 2018-2019 seventh-grade math and seventh- and eighth-grade math and science. Tables 15 shows fifth-grade science OST scores for the 2010-2011 school year for students participating in general education compared to students in the STEM program.

Table 15. Descriptive Statistics for 5th-Grade Science for the 2010-2011 School Year (n= 414)

	Mean	SD	Min.	Max.	Skew.	Kurt.
Gen. Ed. (*n*= 390)	412	26.47	327	527	.23	.72
STEM (*n*= 24)	438	23.79	400	490	.74	.11

Table 16 shows fifth-grade science OST scores for the 2011-2012 school year for students participating in general education compared to students in the STEM program. For the 2010-2011 school year, the mean OST score was considerably higher for STEM students than general education students at 438 and 412, respectively. For both years, the range between the minimum and maximum OST scores was much larger for general education students (min.= 327, max. 527; min. 314, max. 548) compared to STEM students (min. 400, max. 490; min. 404; max. 501), respectively. Both the skewness and kurtosis (ranging from .23 to

.74 and .11 to .72, respectively) were within acceptable limits indicating the data distribution was symmetric and not heavy- or light-tailed. The 2012-2013 school year was the first year OST data were collected for both math and science which continued through the 2018-2019 school year for purposes of this study.

Table 16. Descriptive Statistics for 5th-Grade Science for the 2011-2012 School Year (n= 398)

	Mean	SD	Min.	Max.	Skew.	Kurt.
Gen. Ed. (*n*= 377)	419	30.98	314	548	-.013	.25
STEM (*n*= 21)	447	26.20	404	501	.40	.97

Table 17 displays fifth-grade science, seventh-grade math, and eighth-grade math for the 2012-2013 school year.

Table 17. Descriptive Statistics for 5th-Grade Science and 7th-Grade Math for the 2012-2013 School Year

Test		Mean	SD	Min.	Max.	Skew.	Kurt.
Grade 5 Science	Gen. Ed. (*n*= 365)	411	31.72	318	504	.19	.02
	STEM (*n*= 24)	445	27.00	390	519	.37	1.3
Grade 7 Math	Gen. Ed. (*n*= 424)	422	31.29	346	507	.22	-.52
	STEM (*n*= 28)	442	23.49	390	472	-.46	.63

Similar to previous years, the mean OST score was higher for STEM students with means of 445 for 5th-grade science and 442 for 7th-grade science compared to 411 and 422, respectively. In addition, the range between the minimum and maximum OST scores was significantly larger for general education students for all three tests. For example, for fifth-grade science, the range was 186 points (min.= 318, max. 504) compared to STEM students with a range of 129 (min. 390, max. 519). Both the skewness and kurtosis (ranging from -.46 to .37 and -.52 to .63, respectively) were within acceptable limits indicating the data distribution was symmetric and not heavy- or light-tailed.

Table 18 displays fifth-grade science, seventh-grade math, and eighth-grade math and science for the 2013-2014 school year.

Table 18. Descriptive Statistics for 5th-Science, 7th-Grade Math, 8th-Grade Math, and 8th-Grade Science for the 2013-2014 School Year

Test		Mean	SD	Min.	Max.	Skew.	Kurt.
Grade 5 Science	Gen. Ed. (*n*= 351)	416	27.80	337	492	.02	.33
	STEM (*n*= 22)	448	29.51	388	503	-.22	.46
Grade 7 Math	Gen. Ed. (*n*= 399)	420	30.81	335	543	.40	.84
	STEM (*n*= 25)	449	22.31	407	520	1.08	3.28
Grade 8 Math	Gen. Ed. (*n*= 424)	429	27.57	343	496	-.13	.071
	STEM (*n*= 27)	447	22.42	396	496	-.22	.32
Grade 8 Science	Gen. Ed. (*n*= 425)	413	28.72	333	500	.011	.014
	STEM (*n*= 28)	441	29.96	379	500	-.45	-.10

Similar to previous years, the mean OST score was higher for STEM students with means of 448 for 5th-grade science and 449 for 7th-grade science compared to 416 and 420, respectively. In addition, the range between the minimum and maximum OST scores was significantly larger for general education students for all three tests. For example, for fifth-grade science the range was 155 points (min.= 337, max. 492) compared to STEM students with a range of 115 (min. 388, max. 503). Both the skewness and kurtosis were within acceptable limits for all tests for the 2013-2014 school year that indicated a symmetrical data distribution and all data were fairly mesokurtic.

Table 19 displays all descriptive information of OST scores for the 2014-2015 school year.

Table 19. Descriptive Statistics for 5th- Science, 7th-Grade Math, 8th-Grade Math, and 8th-Grade Science for the 2014-2015 School Year

Test		Mean	SD	Min.	Max.	Skew.	Kurt.
Grade 5 Science	Gen. Ed. (*n*= 349)	704	53.20	376	845	-2.74	14.66
	STEM (*n*=35)	737	40.40	652	820	-.34	-.16
Grade 7 Math	Gen. Ed. (*n*= 384)	725	51.29	327	794	-4.95	30.48
	STEM (*n*= 24)	759	15.71	730	785	-.10	-.86
Grade 8 Math	Gen. Ed. (*n*= 333)	732	44.59	373	810	-4.47	31.35
	STEM (*n*=14)	771	20.70	733	798	-.52	-.61
Grade 8 Science	Gen. Ed. (*n*= 399)	713	50..80	379	823	-2.02	11.66
	STEM (*n*= 25)	759	28.49	720	843	.98	1.54

The mean OST score was higher for STEM students than general education students for all tests in that year. In addition, the range between the minimum and maximum OST scores was significantly larger for general education students for all tests. For example, for seventh-grade math, the range was extremely large at 467 points (min.= 327, max. 794) compared to STEM students with a range of 55 points (min. 730, max. 785). The standard deviations in OST scores were all lower for STEM students further demonstrating the lower ranges among STEM students. The skewness in OST scores for general education students was outside the generally acceptable values ranging from -4.47 to -2.02. Consistently negative skewness to the left indicates the mean was less than the median with fewer very low scores. In addition, the kurtosis for general education students' scores spanned from 11.66 to 31.55, outside of the normal acceptable values indicating the data distribution is leptokurtic with a high ratio of scores gravitating toward the mean in a normal distribution. Only 14 STEM participants took the 8th-grade OST math test as the remaining students took the algebra end-of-course exam. Table 20 displays all descriptive information of OST scores for the 2015-2016 school year.

Table 20. Descriptive Statistics for 5th-Grade Science, 7th-Grade Math, 8th-Grade Math, and 8th-Grade Science for the 2015-2016 School Year

Test		Mean	SD	Min.	Max.	Skew.	Kurt.
Grade 5 Science	Gen. Ed. (*n*=332)	717	47.10	401	845	-1.55	9.38
	STEM (*n*=35)	732	48.92	611	827	-.80	.66
Grade 7 Math	Gen. Ed. (*n*= 358)	700	47.75	408	788	-3.17	16.77
	STEM (*n*= 24)	738	19.57	708	769	-.02	-1.10
Grade 8 Math	Gen. Ed. (*n*= 320)	695	50.38	371	774	-4.38	22.61
	STEM (*n*=16)	732	18.78	692	774	.225	1.38
Grade 8 Science	Gen. Ed. (*n*= 378)	710	61.42	387	849	-2.21	9.63
	STEM (*n*= 23)	761	33.40	678	826	-.21	.54

The mean OST score was higher for STEM students than general education students for all tests in that year. In addition, the range between the minimum and maximum OST scores was significantly larger for general education students for all tests. For example, the range for general education students scores in the eighth-grade science test was significantly larger at 462 points (min.= 387, max. 849) compared to STEM students with a range of 148 points (min. 678, max. 826). The standard deviations in OST scores were all lower for STEM students except for the 5th-grade science test with standard deviations for general education and STEM students being at 47.10 and 48.92, respectively. The skewness in both OST math scores for general education students was outside the generally acceptable values ranging from -3.17 to -4.38. Consistently negative skewness to the left indicates the mean was less than the median with fewer very low scores. Also, the kurtosis for both OST math scores for general education students spanned from 16.77 to 22.61, outside of the normal acceptable values indicating the data distribution is leptokurtic with a high ratio of scores gravitating toward the mean in a normal distribution. Only 16 STEM participants took the 8th-grade OST math test due to the remaining seven students taking the algebra end-of-course exam. Table 21 displays all descriptive information of OST scores for the 2016-2017 school year.

Table 21. Descriptive Statistics for 7th-Grade Math, 8th-Grade Math, and 8th-Grade Science for the 2016-2017 School Year

Test		Mean	SD	Min.	Max.	Skew.	Kurt.
Grade 7 Math	Gen. Ed. (*n*= 342)	701	52.43	382	806	-3.12	16.00
	STEM (*n*=37)	729	44.99	636	806	-.56	-.32
Grade 8 Math	Gen. Ed. (*n*=276)	701	41.36	420	760	-4.26	27.87
	STEM (*n*=15)	728	15.42	709	756	.69	-.99
Grade 8 Science	Gen. Ed. (*n*= 362)	711	49.62	425	811	-2.27	11.13
	STEM (*n*= 24)	757	29.8	697	811	-.09	-.66

The mean OST score was higher for STEM students than general education students for all tests in that year. In addition, the range between the minimum and maximum OST scores was significantly larger for general education students for all tests. For example, the range for general education students scores in the eighth-grade math test was significantly larger at 340 points (min.= 420, max. 760) compared to STEM students with a range of 47 points (min. 709, max. 756). The standard deviations in OST scores were all lower for STEM students. The skewness in both OST math scores for general education students was outside the generally acceptable values ranging from -4.26 to -2.27. Consistently negative skewness to the left indicates the mean was less than the median with fewer very low scores. In addition, the kurtosis for both OST math scores for general education students spanned from 11.23 to 27.87, outside of the normal acceptable values indicating the data distribution is leptokurtic with a high ratio of scores gravitating toward the mean in a normal distribution. Only 15 STEM participants took the 8th-grade OST math test due to the remaining nine students taking the algebra end-of-course exam.

Table 22 displays all descriptive information of OST scores for the 2017-2018 school year.

Table 22. Descriptive Statistics for 7th-Grade Math, 8th-Grade Math, and 8th-Grade Science for the 2017-2018 School Year

Test		Mean	SD	Min.	Max.	Skew.	Kurt.
Grade 7 Math	Gen. Ed. (*n*= 313)	709	38.89	400	806	-1.71	12.18
	STEM (*n*= 36)	727	42.33	636	801	-.48	-.11
Grade 8 Math	Gen. Ed. (*n*= 252)	693	49.16	376	766	-4.51	25.16
	STEM (*n*= 13)	706	32.40	644	747	-.70	-.55
Grade 8 Science	Gen. Ed. (*n*= 328)	715	55.82	385	863	-2.94	15.61
	STEM (*n*= 24)	760	49.88	636	868	-.75	.91

The mean OST score was higher for STEM students than general education students for all tests in that year. In addition, the range between the minimum and maximum OST scores was significantly larger for general education students for all tests. For example, the range for general education students scores in the 7th-grade math test was significantly larger at 406 points (min.= 400, max. 806) compared to STEM students with a range of 165 points (min. 636, max. 801). The standard deviations in OST scores were all lower for STEM students except for the 7th-grade math test with standard deviations for general education and STEM students being at 38.89 and 42.33, respectively. The skewness for both OST 8th-grade tests for general education students was outside the generally acceptable values ranging from -4.51 to -2.94. Consistently negative skewness to the left indicates the mean was less than the median with fewer very low scores. In addition, the kurtosis for both OST math scores for general education students spanned from 15.61 to 25.16, outside of the normal acceptable values indicating the data distribution is leptokurtic with a high ratio of scores gravitating toward the mean in a normal distribution. Only 13 STEM participants took the 8th-grade OST math test due to the remaining 11 students taking the algebra end-of-course exam. Table 23 displays all descriptive information of OST scores for the 2018-2019 school year.

Table 23. Descriptive Statistics for 7th-Grade Math, 8th-Grade Math, and 8th-Grade Science for the 2018-2019 School Year

Test		Mean	SD	Min.	Max.	Skew.	Kurt.
Grade 7 Math	Gen. Ed. (*n*=326)	709	50.91	376	806	-2.35	12.55
	STEM (*n*= 29)	727	34.11	655	806	.04	.06
Grade 8 Math	Gen. Ed. (*n*=276)	703	40.27	373	770	-4.55	32.24
	STEM (*n*= 17)	711	23.18	664	746	-.64	-.14
Grade 8 Science	Gen. Ed. (*n*= 327)	724	50.87	405	836	-2.09	10.43
	STEM (*n*= 34)	761	47.62	651	857	-.60	.27

The mean OST score was higher for STEM students than general education students for all tests in that year. In addition, the range between the minimum and maximum OST scores was significantly larger for general education students for all tests similarly to all previous years in the study. The standard deviations in OST scores were all lower for STEM students. The skewness in scores for all tests involving general education students were outside the generally acceptable values ranging from -4.55 to -2.09. Consistently negative skewness to the left indicates the mean was less than the median with fewer very low scores. In addition, the kurtosis for all OST tests taken by general education students spanned from 10.43 to 32.24, outside of the normal acceptable values indicating the data distribution is leptokurtic with a high ratio of scores gravitating toward the mean in a normal distribution. Only 17 STEM participants took the 8th-grade OST math test due to the remaining students taking the algebra end-of-course exam. The number of STEM participants taking the 8th-grade science assessment was 34 students. Although, there were between 25-28 students per grade level participating in STEM, students who dropped out of the STEM program at the end of seventh grade are identified as STEM students in the study.

Research Question 2:

Do students participating in the integrated middle school STEM program demonstrate differences in achievement due to the interaction effect of gender, race, socioeconomic status, or attendance between the STEM program students and general education students?

Table 24 displays student gender disaggregated by STEM participation for the duration of the study. There were 3,035 general education students and 205 STEM students participating in the study. The ratio of male to female general education students was almost 1:1 with 49.9 to 50.1 percent male to female students, respectively. Among the STEM students the ratio of male to female was 3:2.

Among the 3,032 general education participants who provided race information, the majority of students were White (77.3%), with the second race indicated as Black (13.1%). Other races were represented at significantly lower percentages. Among the 205 STEM participants who provided information on race, the majority were also White (87.3%) with other races, such as Multiracial (6.3%) and Black (3.9%), representing a much lower percentage. The STEM program was less racially diverse than the general education population.

Table 24. Student Gender Disaggregated by STEM Participation for the Entire Study 2010-2011 through 2018-2019

	Gender	Frequency	Percent
Gen. Ed. (*n*= 3035)	Male	1515	49.9
	Female	1520	50.1
	Total	3035	100
STEM (*n*= 205)	Male	123	60
	Female	82	40
	Total	205	100

Table 25 shows the breakdown of student race for students disaggregated by STEM participation.

Table 25. Student Race Disaggregated by STEM Participation for the Entire Study 2010-2011 through 2018-2019

	Race	Frequency	Percent
Gen. Ed. (*n*= 3032)	American Indian	7	.2
	Asian	28	.9
	Black	398	13.1
	Hispanic	119	3.9
	Multiracial	133	4.4
	Puerto Rican	2	.1
	White	2345	77.3
	Total	3032	100
STEM (*n*= 205)	American Indian	0	0
	Asian	1	.5
	Black	8	3.9
	Hispanic	4	2.0
	Multiracial	13	6.3
	Puerto Rican	0	0
	White	179	87.3
	Total	205	100

Table 26 displays SES of general education students and STEM students indicating both the frequency and percent of students economically and not economically disadvantaged.

Table 26. Socioeconomic Status (SES) Disaggregated by STEM Participation for 2010-2011

	SES	Frequency	Percent
Gen. Ed. (*n*= 396)	Not economically disadvantaged	222	56.1
	Economically disadvantaged	174	43.9
	Total	396	100
STEM (*n*= 24)	Not economically disadvantaged	16	66.7
	Economically disadvantaged	8	33.3
	Total	24	100

The percent of students deemed economically disadvantaged was higher in the general education population compared to students in the STEM program for every school year of the study. The variable code in SPSS for students deemed not economically disadvantaged was SES=0. This created validity errors as missing information was entered as zero during data processing. Therefore, the percent of students identified as not economically disadvantaged is higher than the state-reported economically disadvantaged percentages that range from 51% to 54% depending upon the year. The remaining tables displaying descriptive statistics for subsequent years are located in Appendix C due to redundancy and lack of relevance. This is discussed as a limitation in Chapter 5.

Table 27 displays the descriptive statistics for attendance rate of general education students and STEM students for the 2010-2011 school year.

Table 27. Descriptive Statistics for Student Attendance in the 2010-2011 School Year

	Mean	SD	Min.	Max.	Skew.	Kurt.
Gen. Ed. (*n*= 396)	.9570	.0341	.79	1.00	-1.32	2.13
STEM (*n*= 24)	.9470	.0373	.85	.99	-1.15	.62

There were relatively small differences in the mean attendance rate between general education and STEM students with higher attendance among general education students in 2010-2011 school year. There was a higher mean attendance among STEM students all the other remaining years. The remaining tables displaying descriptive statistics for subsequent years are located in Appendix B due to redundancy and lack of relevance. This is expanded upon in Chapter 5.

Inter-correlations between Variables

Preliminary bivariate relationships between STEM participation and student-level variables were determined using SPSS (V. 26) and are displayed in Tables 28, 29, and 30. Table 28 shows the Pearson correlation coefficients between student-integrated STEM participation and the student-level coded variables of GENDER and RACE. Out of the 3,237 and 3,240 students with data for GENDER and RACE, the Pearson bivariate correlation was extremely low (*r*= 0.069 and -.049, respectively) indicating a lack of practical significance. The *r* values, although statistically significant, are inflated due to the very large sample size of participants in the study. Therefore, there is no practical significance between these student-level variables and STEM participation.

Table 28. Pearson Correlation between STEM Participation and Student-level Variables Independent of School Year

Variable	STEM	Sig. (2-tailed)	N
STEM	1		3240
RACE	.069*		3237
GENDER	-.049**	0.005	3240

Table 29 shows the Pearson correlation coefficients between student-integrated STEM participation and the student-level coded variable of SES by school year. For every school year, the number of students with socioeconomic information ranged from 405 for the 2011-20112 year to 1253 for the 2012-2013 school year due to the number of participants with OST data. The bivariate correlation was extremely low and lacking significance every year ranging from -.08 to 0.02. This indicates a lack of correlation between the student-level variable of socioeconomic status and STEM participation.

Table 29. Pearson Correlation between STEM Participation and SES by School Year

Variable	STEM	Sig. (2-tailed)	N
Y2010_SES	-0.05	0.31	420
Y2011_SES	-0.06	0.227	405
Y2012_SES	-0.071*	0.04	842
Y2013_SES	-.059*	0.037	1253
Y2014_SES	-.068*	0.018	1222
Y2015_SES	-0.048	0.101	1153
Y2016_SES	-0.013	0.728	767
Y2017_SES	0.02	0.612	621
Y2018_SES	-.080*	0.032	723

The Pearson correlation coefficient between student integrated STEM participation and the student-level coded variable of attendance rate by school year is shown in Table 30. For every school year, the number of students with attendance data ranged from 405 for the 2011-2012 year to 1,253 for the 2012-2013 school year due to the number of participants with OST data. The bivariate correlation was extremely low and of no practical significance every year ranging from -.065 to 0.07. This indicates a weak correlation between the student-level variable of attendance rate and STEM participation.

Table 30. Pearson Correlation between STEM Participation and Attendance by School Year

Variable	STEM	Sig. (2-Tailed)	N
Y2010_ATTEND	-0.065	0.183	420
Y2011_ATTEND	0.063	0.208	405
Y2012_ATTEND	0.021	0.535	842
Y2013_ATTEND	0.016	0.568	1253
Y2014_ATTEND	0.05	0.092	1146
Y2015_ATTEND	0.102**	0.001	1081
Y2016_ATTEND	-0.043	0.271	669
Y2017_ATTEND	0.017	0.682	601
Y2018_ATTEND	0.07	0.079	623

Hierarchical Linear Modeling Related to Research Questions

The research question addressed in this study is to determine the impact of middle school integrated STEM programming on student performance and achievement. Currently, little research has been conducted on the impact of STEM programming and instruction on student academic performance and achievement. The primary research question to be addressed in this research is as follows:

> Does middle school integrated STEM programming positively affect student achievement?

The additional five research questions related to the primary question are stated below with the HLM data presented pertaining to each research question.

Research Question 1

Do students participating in an integrated middle school STEM program demonstrate differences in academic achievement in math and science compared to students participating in a traditional general education setting?

Research question one can be broken down into two sub-questions.

Sub-question 1:

Do students participating in an integrated middle school STEM program demonstrate differences in academic achievement in both math and science?

Model 1- Academic Achievement by Year

The use of HLM to determine the effect of integrated STEM programming on student achievement was modeled using different variables at level-1 and level-2. The first model used OST score (SCALEDSC) and STEM participation (STEMMARK) at level-1 and the assessment type indicated by year (ASSMTTYP) as level-2. Table 31 displays descriptive statistics for level-1. There were 8,874 data points at level-1 with a mean scaled score of 598.94. The test scores are mutually exclusive for individual subjects, grades, and years but HLM accounts for this by nesting the data within level-2.

Table 31. Model 1: Level-1 Descriptive Statistics

Variable Name	N	Mean	SD	Min.	Max.
STEMMARK	8874	0.06	0.24	0.00	1.00
SCALEDSC	8874	598.94	149.06	314.00	868.00

Table 32 displays Model 1 descriptive statistics for level-2. There were nine assessment types indicated by years of the study.

Table 32. Model 1: Level-2 Descriptive Statistics

Variable Name	N	Mean	SD	Min.	Max.
ASSMTTYP	9	1.22	0.44	1.00	2.00

Equation 6 displays the HLM equation at level-1, OST scores are shown as the outcome variable ($SCALEDSC_{ij}$) and STEM participation (($STEMMARK_{ij}$) is the level-1 predictor variable. Equation 7 shows level-2 with assessment type ($ASSMTTYP_j$) as the level-2 predictor variable.

Level-1 Model

$$SCALEDSC_{ij} = \beta_{0j} + \beta_{1j}*(STEMMARK_{ij}) + r_{ij} \quad (6)$$

Level-2 Model

$$\beta_{0j} = \gamma_{00} + \gamma_{01}*(ASSMTTYP_j) + u_{0j} \quad (7)$$

$$\beta_{1j} = \gamma_{10}$$

The mixed model below (Equation 8) substitutes the intercept of the *j*th level-2 (β_{0j}) from Equation 7 into Equation 6 to get the mixed model shown below (Equation 8). The combined model contains both the level-1 and level-2 predictors and a term across levels containing both random and fixed effects unique to HLM analysis. The analysis of variance (ANOVA) model was used to determine the mean achievement scores among both general education students and students participating in a STEM program and compare the differences.

This was performed to measure the variation between student-level and grade-level assessment groups. This mixed model, combining both fixed and random effects, was used to analyze the relationship between student achievement as a function of STEM programming versus general education programming. The proposed mixed model was found to be significant in predicting student achievement as a function of the defined level-1 and level-2 variables as shown below in Table 33 and Table 34.

Mixed Model

$$SCALEDSC_{ij} = \gamma_{00} + \gamma_{01}*ASSMTTYP_j + \gamma_{10}*STEMMARK_{ij} + u_{0j} + r_{ij} \quad (8)$$

The final estimation of fixed effects with robust standard errors for Model 1 are shown in Table 33.

Table 33. Model 1: Final Estimation of Fixed Effects (with Robust Standard Errors)

Fixed Effect	Coefficient	Standard error	t-ratio	Approx. d.f.	p-value
For INTRCPT1, β_0					
INTRCPT2, γ_{00}	836.77	99.32	8.43	7	<0.001
ASSMTTYP, γ_{01}	-211.11	49.72	-4.25	7	0.004
For STEMMARK slope, β_1					
INTRCPT2, γ_{10}	31.33	2.29	13.69	8864	<0.001

Fixed effects were used because the level-2 group was a unique entity and *j* was small indicating the number of years ($j<10$). Robust standard errors were used for both Model 1 and Model 2 due to confidence in the distribution of the dependent variable of assessment type at level-2. The overall mean intercept adjusted for student achievement by year (ASSMTTYP) for STEM students (STEMMARK) was determined to be 31.3 (INTRCPT2, γ_{10}), indicating a significant correlation between STEM participation and student achievement. Student achievement as indicated by OST scores for a given year, grade, and subject indicate that a STEM student was predicted to score 31.3 points higher than general education students. All p-values are statistically significant ($p \leqq 0.004$) supporting the correlation between STEM program participation and student achievement. The final estimation of variance shown in Table 34 displays the random error associated with the use of the final estimation of fixed effects. The random effect at level-1 has a standard deviation of 44.68.

Table 34. Model 1: Final Estimation of Variance Components

Random Effect	Standard Deviation	Variance Component	*d.f.*	χ^2	*p*-value
INTRCPT1, u_0	131.48	17285.64	7	74797.10	<0.001
level-1, *r*	44.68	1996.36			

Sub-question 2:

Do students participating in an integrated middle school STEM program demonstrate differences in academic achievement in science?

Model 2- Comparing 5th- and 8th-Grade Science

The goal of the second model was to effectively predict the OST score for students taking both the fifth grade and eighth grade science OST tests as a function of STEM participation. The model used OST score (SCALEDSC) and STEM participation (STEMMARK) at level-1 (similar to Model 1) and the assessment type indicated by year (GRADE) as level-2. Table 35 displays descriptive statistics for both level-1.

Table 35. Model 1: Level-1 Descriptive Statistics

Variable Name	N	Mean	SD	Min.	Max.
STEMMARK	4048	0.06	0.24	0.00	1.00
SCALEDSC	4048	562.50	156.94	314.00	868.00

There were 4,048 data points at level-1 with a mean scaled score of 562.50. The test scores are mutually exclusive for individual grades and years but HLM accounts for this by nesting the data within level-2.

The descriptive statistics at level-2 are shown in Table 36. There were nine science assessments indicated by the variable GRADE occurring over the course of the study beginning in 2010-2011 and ending in 2018-2019. The minimum value was 5 indicating fifth grade and the maximum value was 8 indicating eighth grade.

Table 36. Model 2: Level-2 Descriptive Statistics

Variable Name	N	Mean	SD	Min.	Max.
GRADE	9	6.00	1.50	5.00	8.00

Equation 9 displays the HLM equation at level-1, OST scores are shown as the outcome variable ($SCALEDSC_{ij}$) and STEM participation (($STEMMARK_{ij}$) is the level-1 predictor variable. Equation 10 shows level-2 with science assessment ($GRADE_j$) as the level-2 predictor variable.

Level-1 Model

$$SCALEDSC_{ij} = \beta_{0j} + \beta_{1j}*(STEMMARK_{ij}) + r_{ij} \quad (9)$$

Level-2 Model

$$\beta_{0j} = \gamma_{00} + \gamma_{01}*(GRADE_j) + u_{0j} \quad (10)$$

$$\beta_{1j} = \gamma_{10}$$

The mixed model in Equation 11 substitutes the intercept of the *j*th level-2 (β_{0j}) from Equation 10 into Equation 9 to get the mixed model shown below (Equation 11). This model was found to be significant in predicting student achievement as a function of the defined level-1 and level-2 variables as shown below in Table 37 and Table 38.

Mixed Model

$$SCALEDSC_{ij} = \gamma_{00} + \gamma_{01}*GRADE_j + \gamma_{10}*STEMMARK_{ij} + u_{0j} + r_{ij} \quad (11)$$

The final estimation of fixed effects with robust standard errors for Model 2 are shown in Table 37.

Table 37. Model 2: Final Estimation of Fixed Effects (with Robust Standard Errors)

Fixed Effect	Coefficient	Standard error	*t*-ratio	Approx. *d.f.*	*p*-value
For INTRCPT1, β_0					
INTRCPT2, γ_{00}	170.67	151.51	1.13	7	0.297
GRADE, γ_{01}	68.17	18.98	3.59	7	0.009
For STEMMARK slope, β_1					
INTRCPT2, γ_{10}	38.19	3.14	12.17	4038	<0.001

The overall mean intercept adjusted for student achievement by year (ASSMTTYP) for STEM students (STEMMARK) was determined to be 38.2 (INTRCPT2, γ_{10}), indicating a significant correlation between STEM participation and student achievement as evidenced by fifth grade to eighth grade science OST scores. Student achievement measured by OST scores for fifth and eighth grade science predicted STEM students will score 38.2 points higher than general education students. This correlation was stronger than all assessment types used in Model 1. All p-values are statistically significant ($p \leqq 0.009$) supporting the correlation between STEM program participation and student achievement in science except for INTRECPT2, γ_{00} with a p-value of 0.297.

The final estimation of variance shown in Table 38 displays the random error associated with the use of the final estimation of fixed effects. The standard deviations in the random effect associated with level-1, r was 45.42 and an INTRCPT1, u_0 of 128.88.

Table 38. Model 2: Final Estimation of Variance Components

Random Effect	Standard Deviation	Variance Component	*d.f.*	χ^2	*p*-value
INTRCPT1, u_0	128.88	16608.96	7	25720.24	<0.001
level-1, r	45.42	2062.89			

The remaining research question sought to determine if students participating in an integrated middle school STEM program demonstrated differences in academic achievement due to the interaction effect of student gender, race, socioeconomic status, and attendance.

Research Question 2

Do students participating in the integrated middle school STEM program demonstrate differences in achievement due to the interaction effect of gender, race, socioeconomic status, or attendance between the STEM program students and general education students?

Previously in this chapter, preliminary bivariate relationships between STEM participation and student-level variables of gender, race, socioeconomic status, and attendance were determined and displayed in Tables 28, 29, and 30. Pearson correlation coefficients between student achievement and all student-level variables were extremely low indicating no significant relationship and correlation between these student-level variables and STEM participation.

Chapter Summary

Chapter 4 displays the variable and sample descriptions with descriptive statistics related to each research question. The descriptive statistical information for OST scores by year are displayed indicating the mean, standard deviation, minimum score, maximum score, skewness, and kurtosis for each subject, grade level, and year. The inter-correlation between variables were shown with preliminary bivariate relationships indicated by Pearson correlation coefficients. Two HLM models were created addressing the research questions to determine differences in achievement among the multilevel data of students, located in a classroom, nested in a grade level, and found within a school.Chapter 5 discusses the summary of the findings as they pertain to each research question along with limitations, implications for practice, and directions for future practice.

Citation

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CHAPTER 5: IMPLICATIONS FOR STUDENT AND SCHOOL EFFECTS ON ACADEMIC ACHIEVEMENT IN A STEM PROGRAM

> *"Research shows that there is only half as much variation in student achievement between schools as there is among classrooms in the same school. If you want your child to get the best education possible, it is actually more important to get him [or her] assigned to a great teacher than to a great school."*
>
> Bill Gates (date unknown)

Summary of Findings

A summary of findings is explained as it pertains to each research question addressed in this study to determine the impact of middle school integrated STEM programming on student performance and achievement. The impetus of this research was due to the lack of research conducted on the impact of STEM programming and instruction on student academic performance, particularly achievement. The summary of findings indicate significant differences in student achievement in math and science with students participating in STEM performing markedly higher than students in the general education setting. Preliminary bivariate relationships between STEM participation and the student-level variables of gender, race, socioeconomic status, and attendance were determined to be extremely low indicating no significant relationship or correlation between these variables and student achievement.
An explanation and summary of findings for the proposed research questions are explained below.

The primary research question to be addressed in this research is as follows:

> Does middle school integrated STEM programming positively affect student achievement?

Research Question 1

Do students participating in an integrated middle school STEM program demonstrate differences in academic achievement in math and science compared to students participating in a traditional general education setting?

The remaining research questions discussed in previous chapters sought to determine if students participating in an integrated middle school STEM program demonstrated differences in academic achievement due to the interaction effect of student gender, race, socioeconomic status, and attendance. These were combined into one research question due to the lack of interaction effect found. Therefore, the remaining four research questions in this study were combined into one all-encompassing research question shown below.

Research Question 2

Do students participating in the integrated middle school STEM program demonstrate differences in achievement due to the interaction effect of gender, race, socioeconomic status, or attendance between the STEM program students and general education students?

Research Question 1 Findings

Do students participating in an integrated middle school STEM program demonstrate differences in academic achievement in math and science compared to students participating in a traditional general education setting?

Mathematics and Science Achievement

Past research has determined the impact of STEM education policies and initiatives on student achievement having varying degrees of success (Dugger, 2010; Gonzalez & Kuenzi, 2012; Snyder, 2018; White, 2014). Although Gonzalez and Kuenzi (2012) reported there is no single statistic that can fully quantify the success of STEM education on a national, state, or local level, this study attempted to gain insight into the impact of STEM education on student achievement at a school and student level. Quantifying student achievement via the OST, a norm-referenced statewide assessment, is the gold standard for measuring student achievement and is the primary indicator of achievement in all previous literature discussed.

There were three research studies similar to this study found in recent literature. First, Wade-Shepard (2016) investigated the effect of middle school STEM curriculum on both science and math achievement scores. The research was conducted among four schools of seventh and eighth grade students in Tennessee using the Tennessee Comprehensive Assessment Program (TCAP). Instead of performing HLM for data analysis, Wade-Shepherd (2016) used two ANCOVAs and the Pearson correlation to determine the strength of the relationship between mathematics and science scores of students participating in STEM education classes and those that were not participating. The study did not include data analysis of other moderators of achievement, such as attendance, demographic information, and teacher efficacy. The study found a significant, strong, and positive correlation between test scores of students participating in STEM classes compared to those that were not taking STEM classes across the four schools (Wade-Shepard, 2016).

The second research study by Hansen and Gonzalez (2014) investigated the relationships between STEM learning principles, such as PBL and student achievement in math and science. This mixed methods study included middle school students in North Carolina and used a combination of quantitative state assessment and qualitative student survey data. The study found specific STEM practices were associated with performance gains in math and science. For example, projects and science experiments were associated with higher scores in science and the use of technology and computers were associated with higher scores in math. In addition, these significant and positive correlations were also found among racial minorities (Hansen & Gonzalez, 2014).

The third research study analyzed both STEM curriculum and PBL strategies on student mathematics performance disaggregated by low, middle, and high achieving students to determine the degree of effect as a function of student achievement level (Han et al., 2015). The study took place in Texas among three high schools with students in the treatment group participating in STEM PBL activities once every six weeks over the course of three years. This study was similar to the current study as it used HLM to determine the effect of STEM PBL activities on students' mathematics scores accounting for student moderators such as student socioeconomic status and race. Han et al. concluded lower achieving students showed a statistically significant higher rate of growth on math scores compared to middle and high performing students over the course of three years. They also found student race and socioeconomic status were strong predictors of student academic achievement (Han et al.).

Although student race and socioeconomic status are often correlated with student growth and achievement similar to what was reported by Han et al., the present study did not conclude similar results to support the claims in previous literature.

This study was a combination of the above three studies summarized above studying both science and math achievement, similar to Wade-Shepard (2016) and Hansen and Gonzalez (2014). In addition, this study used HLM and also analyzed the effect of demographic moderators, similar to Han et al. (2015). The results of this study indicate through comparison of descriptive statistics and HLM analysis that middle school students participating in integrated STEM programming scored significantly higher on the OST compared to their general education peers.

In this study, Model 1 used OST score (SCALEDSC) and STEM participation (STEMMARK) at level-1 and the assessment type by year (ASSMTTYP) at level-2. Descriptive statistics indicated all participants at level-1 (n=8874) had a mean OST score of 598. The singular level-2 variable (ASSMTTYP) clustered the level-1 participants into nine groups (n=9) for each tested year beginning in the school year 2010-2011 through 2018-2019 creating a longitudinal sample analysis. A mixed model, containing both fixed and random effects, combined both the level-1 and level-2 predictors and was found to be significant in predicting student achievement as a function of STEM participation for a given tested year cluster. The overall mean intercept adjusted for student achievement by year (ASSMTTYP) for STEM students (STEMMARK) was determined to be 31.3 points (INTRCPT2, γ_{10}), indicating a significant correlation between STEM participation and student achievement. Student achievement as indicated by OST scores for a given year, grade, and subject indicate that a STEM student is predicted to score 31.3 points higher than general education students. All p-values were significantly small ($p \leqq 0.004$) supporting the correlation between STEM program participation and student achievement.

Science Achievement

This study used HLM to determine the effect STEM programming had on student achievement. Students took the OST science tests only in the fifth and eighth grade. Because the STEM program began in the seventh grade for the duration of the study, STEM students had two years of STEM programming by the time they took the eighth grade test. The use of

HLM to determine student achievement as a function of STEM programming was powerful when comparing scores from the fifth to eight grade.

One study, published by Gabriel and Quinlin (2016), sought to determine the effect of Project Lead the Way (PLTW) curriculum on the 2016 Missouri Assessment Plan Science scores of fifth and eighth grade students. This study included mid-range socioeconomic students only across two school districts comparing test scores of students exposed to the PLTW curriculum and those that were not exposed to the curriculum. The study used a basic *t*-test and determined there was a significant, positive effect of STEM programming, particularly PLTW on student achievement (Gabriel & Quinlin, 2016).

In this study, Model 2 used OST score (SCALEDSC) and STEM participation (STEMMARK) at level-1 (similar to Model-1) and the science assessment type indicated by year (GRADE) at level-2. Descriptive statistics indicated all participants at level-1 (n=4048) had a mean OST score of 562 points. The singular level-2 variable (GRADE) clustered the level-1 participants into nine groups (n=9) for each tested year of science only beginning in the school year 2010-2011 through 2018-2019 creating a longitudinal sample analysis. A mixed model, containing both fixed and random effects, combined both the level-1 and level-2 predictors and was found to be significant in predicting student achievement as a function of STEM participation for a given tested year cluster. The overall mean intercept adjusted for student achievement by year (ASSMTTYP) for STEM students (STEMMARK) was determined to be 38.2 (INTRCPT2, γ_{10}), indicating a significant correlation between STEM participation and student achievement in science. Student achievement as indicated by OST scores for a given year, grade, and subject indicate that a STEM student is predicted to score 38.2 points higher than general education students. All p-values are statistically significant ($p \leqq 0.009$) supporting the correlation between STEM program participation and student achievement in science except for INTRECPT2, γ_{00} with a p-value of 0.297.

The predictive results of Model 2 indicate through comparison of descriptive statistics and HLM analysis, that middle school students participating in integrated STEM programming scored significantly higher on the OST in science compared to their general education peers scoring above 38.2 points higher on average. The impact of STEM participation on student achievement was stronger when comparing science only in Model 2 (INTRCPT2, $\gamma_{10} = 38.2$)

compared to both math and science achievement in Model 1 (INTRCPT2, $\gamma_{10} = 31.8$), respectively.

Research Question 2 Findings

The remaining research questions discussed in previous chapters sought to determine if students participating in an integrated middle school STEM program demonstrated differences in academic achievement due to the interaction effect of student gender, race, socioeconomic status, and attendance. These were initially separated into four research questions by factors; gender; race; socioeconomic status, and attendance in the previous chapters. For simplicity and to prevent redundancy, the research questions were combined into one research question due to the lack of interaction effect found. The remaining four research questions in this study were combined into one all-encompassing research question shown below.

> ***Research Question 2***
> Do students participating in the integrated middle school STEM program demonstrate differences in achievement due to the interaction effect of gender, race, socioeconomic status, or attendance between the STEM program students and general education students?

Student Achievement and Interaction Effects

Past research indicates mixed results regarding the impact of STEM education due to interaction effects such as gender, socioeconomic status, race, and attendance on student achievement (Dugger, 2010; Gonzalez & Kuenzi, 2012; Snyder, 2018; White, 2014). The most similar study to the present one conducted by Han et al. (2015) concluded student race and socioeconomic status were strong predictors of student achievement in math and science. In addition, Hansen and Gonzalez (2014) determined positive gains in achievement among underrepresented racial minorities. This present study produced inconclusive results quantifying the impact of the potential moderators of gender, socioeconomic status, race, and attendance.

Preliminary bivariate relationships between STEM participation and student-level variables of gender, socioeconomic status, race, and attendance were determined using Pearson correlation coefficients. All Pearson *r* values were extremely low (ranging from -0.068 to 0.102) indicating no practical significance in the relationship or correlation between these student-level variables and STEM participation.

Limitations

There were two types of limitations; one type involved the data collection process and human factors and the other type was due to the method of data analysis through multilinear modeling and HLM.

The data collection process posed a few limitations. First, there was a substantial amount of missing data for the SES of students. Missing data values were initially coded as 0, therefore yielding a higher percentage of students deemed not economically disadvantaged. The percent range of economically disadvantaged students for the school for each year of the study was 51% to 54% (ODE, 2019). However, the economically disadvantaged percent range for general education students for the duration of this study was 38.8% to 47.3%, respectively. This was significantly lower than reported indicating an overidentification of students deemed not economically disadvantaged. Another limitation in data collection was several participants were missing attendance data for any given year. This posed substantial inaccuracy in determining the effect of attendance as a moderator of student achievement supporting inconclusive results. A further limitation in data collection was the self-reporting of student race data by parents.

Student mortality is another limitation of the study. The last year for fifth grade science scores was 2014-2015 because the last year of the study was 2018-2019 with those participants as eighth grade students. The number of participants for science tests ranged from 327 (8^{th}-grade science for 2018-2019) to 425 (8^{th}-grade science for 2013-2014) for general education students and 15 (8^{th}-grade math for 2016-2017) to 35 (5^{th}-grade science for 2014-2015) for STEM students. Although, each STEM class consisted of 25-28 students per grade level, the number of STEM students with 5^{th}-grade science scores was larger than that due to mortality in the program and students identified as STEM students, although they were no longer participating. Fortunately, participant mortality was low with only two to three participants per school year. In addition, the number of participants was substantially lower for math tests due to eighth grade students taking the OST end-of-course exam in algebra in lieu of the 8^{th}-grade math test.

Lastly, a handful of students dropped out of the STEM program in the seventh grade and were counted as STEM students as eighth graders. Therefore, migration of students out of the program, although a small number of participants, posed both internal validity and reliability threats.

There were a few limitations due to the research methodology. First, because this research was a case study involving only one school there are limitations regarding generalizability due to limited external validity. The present study was longitudinal over the course of seven years, therefore, it provided a clearer view of the impact of STEM programming on the specific population. A second limitation was a limited number of STEM teachers providing the treatment of the study. Therefore, it may be difficult to determine if the differences in achievement between STEM and general education students were due to STEM programming or teacher-related factors. Teacher efficacy, defined by an educator's own belief that students can learn and overcome challenges, is the most important and powerful factor influencing student achievement (Hattie, 2009). Because the STEM program contained few teachers, the impact of the treatment on student performance may have been due to individual teacher efficacy. The influence of teacher collective efficacy on student achievement had a reported effect size of 1.57, more than double the effect size of other reported impactful factors, such as programming (Hattie, 2009). In regard to teacher efficacy and STEM programming, specifically, Chai et al. (2019) found teachers' comfortability with technological pedagogical knowledge to be the strongest predictor of teacher efficacy among STEM educators.

The last limitation related to the methodology of the study is many STEM students were already high achieving prior to participating in the program. This is evidenced by the mean OST scores in science for fifth grade STEM students being larger than the mean of general education students for all tests in the study. Therefore, the impact of STEM programming may be more difficult to determine due to students already being higher achieving on average prior to participating in the STEM program in seventh and eighth grades.

Implications for Practice

The findings indicate integrated STEM programming had a positive impact on middle school students and increases both science and math performance. This has powerful implications for educational leaders, particularly with changes in legislation that gave more power to local school districts and increased funding under ESSA (Achieve, 2015; ESSA, 2015). Therefore, it is important educational leaders are aware of the impact integrated STEM programming and PBL has on student achievement. In addition, due to the increase in funding for STEM education there are many STEM curriculum companies promising quality technological curriculum, such as PLTW. This research will assist educational leaders in making the appropriate fiscal decisions regarding the purchasing of effective STEM programming and professional development for teachers. Bybee (2013) discussed major challenges specific to STEM education stating these are related to the misunderstandings surrounding the definition of STEM education and the qualifications of STEM literacy. The themes related to reform according to Bybee (2013) include:

- focusing on global challenges with citizen understanding,
- changing societal views of environmental issues,
- identifying 21st-century skills in the workforce, and
- challenges facing national security.

School leaders play an important and foundational role in ensuring the implementation and sustainability of STEM reform (Bybee, 2013; Waight et al., 2018). The impact STEM education and technological literacy has on challenges facing all citizens around the world, such as fighting a global pandemic and world-wide climate change, is important. Decisions made by legislators and school leaders are crucial in ensuring the implementation and sustainability of STEM reform (Bybee, 2013; Waight et al.2018).

Research findings are continuing to support a strong impact of integrated STEM programming on student achievement at the middle school level. The interdisciplinary method of teaching STEM provides students learning concepts and skills from two or more disciplines that are tightly linked to deepen knowledge and skills (Kaufman et al., 2003). Other methods of teaching STEM previously discussed by Kaufman et al. include: disciplinary, multidisciplinary, and transdisciplinary. An implication of this research would be to determine the effectiveness of other STEM methods on student achievement.

There were two implementation dichotomies discussed previously: isolation versus integration and "Some STEM for All" versus "All STEM for Some". This research further demonstrates the success of STEM on student achievement using the integration model, a method supported by many in previous research literature (Dugger, 2010; Sanders, 2009). In addition, this research analyzed the success of a STEM program model utilizing the "All STEM for Some" approach described and supported by Atkinson (2012) and Elrod et al. (2012) particularly at higher grade levels.

The argument among researchers is not whether integrated STEM education is effective at the elementary, middle, or high school level, but rather which grade level is most impactful for the introduction of STEM practices on student achievement, and subsequently, future success. Both the elementary and high school years have been shown to be powerful in regard to shaping students' perceptions of their learning and impact on the development of integrated STEM education practices. Somewhere between the two may be the "goldilocks" zone, the middle school years, when students are beginning to develop attitudes and beliefs regarding their abilities in STEM and possibilities of future careers (Christensen et al., 2015). This research study supports the positive impact STEM programming has during the middle school years.

The National Middle School Association (NMSA, 2010) recommended integrated STEM curriculum and instruction at the middle school level as it offers engaging and holistic instruction for all learners with studies finding the integration of mathematics and science having a positive influence on students' attitudes toward school, their motivation to learn, and academic performance. Moreno et al. (2016) remarked, "The middle school years are a crucial time for cultivating students' interest in and preparedness for future STEM careers" (p. 889). Middle school is a pivotal time for students as their viewpoints on education and careers are greatly impacted by their environment and their focus shifts to future careers. This research further supports the importance of middle school STEM in shaping students' perspectives on future careers.

Considerations for Future Practice and Research

There are several considerations regarding directions for future practice and research expanding upon this research study. First, an extension of this present study would be to determine the differences in OST scores among low, middle, and high achieving students as a function of STEM participation. Han et al. (2015) found low achieving students exposed to STEM programming experienced the most growth in achievement compared to their middle and higher achieving peers. Disaggregating student achievement by performance level would gain deeper information into the impact of STEM on student achievement on different levels of learners.

Another consideration for future research would be to determine teachers' individual self-efficacy for the few educators providing the STEM programming to students in the study. In addition, the quality of STEM and PLTW training should be researched. An expansion upon this would be to determine the technological pedagogical knowledge of the teachers providing STEM programming to determine their individual impact on student achievement. Han et al. (2015) conducted an analysis determining the different types of content knowledge necessary to be a successful STEM educator. This model called the Technological Pedagogical Content Knowledge (TPACK) framework assesses teachers' self-efficacies to determine their impact on student achievement. Collecting TPACK information and survey data on STEM teachers would strengthen the results of the impact integrated STEM education has on student achievement. The influence of individual teachers is often more pronounced than the collective influence of a school or program. Bill Gates, a businessman, software developer, and philanthropist summarized the power of teacher impact stating:

> Research shows that there is only half as much variation in student achievement between schools as there is among classrooms in the same school. If you want your child to get the best education possible, it is actually more important to get him [or her] assigned to a great teacher than to a great school. (Gates, n.d.)

The variability of student performance as a function of STEM participation may have more to do with the quality of the educator than the STEM programming itself. Future research needs conducted to determine the depth of teacher efficacy on student achievement in STEM education.

This research study was conducted to determine the effectiveness of integrated STEM education on student achievement and, subsequently, student future success. The need for STEM education was ignited by the Space Race of the 1950s and gained momentum due to *A Nation at Risk* and the development of the AAAS in the 1980s. STEM education is resurging and breathing new life due to urgent needs in medical, scientific, and technological advancements prompted by the recent coronavirus pandemic. This research on the importance of STEM education will not only create a pathway to success for students but shape competent adults able to carry the nation through an unforeseeable future.

Conclusion

This longitudinal study reported OST scores along with demographic factors such as gender, socioeconomic status, race, and attendance to determine the impact of STEM programming on specific populations of middle school students. The use of multilevel, statistical analysis through HLM determined integrated STEM programming had a significant, positive effect on student achievement in both math and science, and an even stronger impact isolating science achievement by itself. The predictive results of HLM analysis determined STEM students scored significantly higher on the OST in science and math combined scoring 31.8 points higher on average and 38.2 points higher in science compared to their general education peers. No interaction effects were determined between STEM participation and gender, socioeconomic status, student race, and attendance rate. More research needs conducted on the impact of teacher efficacy, individual classroom influences, and quality of STEM training for educators. The research results indicate that integrated STEM programming in middle school had a positive effect on student achievement indicating it is indeed a pathway to success.

Chapter Summary

A summary of findings is explained as it pertains to each research question addressed in the study to determine the impact of middle school integrated STEM programming on student performance and achievement. The results indicate significant differences in student achievement in math and science with students participating in STEM performing markedly higher than students in the general education setting. Preliminary bivariate relationships between STEM participation and the student-level variables of gender, race, socioeconomic status, and attendance were determined to be extremely low indicating no practical significant relationship or correlation between these variables and student achievement.The predictive results of HLM analysis determined STEM students scored significantly higher on the OST in science and math combined scoring 31.8 points higher on average and 38.2 points higher in science compared to their general education peers. No interaction effects were determined between STEM participation and gender, socioeconomic status, student race, and attendance rate. More research needs conducted on the impact of teacher efficacy, individual classroom influences, and quality of STEM training for educators. The research results indicate that integrated STEM programming in middle school had a positive effect on student achievement indicating it is indeed a pathway to success.

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APPENDIXES

Appendix A. Acronyms

AAAS	American Association for the Advancement of Science
AASBD	All-American Soap Box Derby
ACC	Academic Competitiveness Council
AETL	Advancing Excellence in Technological Literacy
AIR	American Institute of Research
ANCOVA	Analysis of Covariance
API	Appalachia Partnership Initiative
DARPA	Defense Advanced Research Projects Agency
ED	Departments of Education
EbD	Engineering by Design
ELA	English Language Arts
EMIS	Education Management Information System
ESSA	Every Student Succeeds Act
FPO	Falcon Pride Online
GRC	Gravity Racing Challenge
HHS	Health and Human Services

HLM	Hierarchical Linear Modeling
HOPE	Helping Others Pursue Excellence
i3	Investing in Innovation
IPEDS	Integrated Postsecondary Education Data System
IRB	International Review Board
ISHS	Inclusive STEM High School
ITEA	International Technology Education Association
ITEST	Innovative Technology Experiences for Students and Teachers
NAEP	National Assessment of Educational Progress
NASA	National Aeronautics and Space Administration
NCLB	No Child Left Behind
NCTM	National Council of Teachers of Mathematics
NRC	National Research Council
NSF	National Science Foundation
ODE	Ohio Department of Education
OLS	Ordinary Least Squares Regression
OST	Ohio State Tests
PARCC	Partnership for Assessment of Readiness for College and Careers
PCAST	President's Council of Advisors on Science and Technology
PBL	Project-Based Learning
PLTW	Project Lead the Way
SMET	Science, Math, Engineering, Technology

SSAE	Student Success and Academic Enrichment Grants
SSID	Student State Identification
STEM	Science, Technology, Engineering, Math
STL	Standards for Technology Literacy
TCAP	Tennessee Comprehensive Assessment Program
TfAAp	Technology for All Americans Project
TPACK	Technological Pedagogical Content Knowledge

Appendix B. Descriptive Statistics for Socioeconomic Status

Socioeconomic status (SES) disaggregated by STEM participation for 2011-2012

	SES	Frequency	Percent
Gen. Ed. (*n*= 384)	Not economically disadvantaged	223	58.1
	Economically disadvantaged	161	41.9
	Total	382	100
STEM (*n*= 21)	Not economically disadvantaged	15	71.4
	Economically disadvantaged	6	28.6
	Total	21	100

Socioeconomic status (SES) disaggregated by STEM participation for 2012-2013

	SES	Frequency	Percent
Gen. Ed. (*n*= 790)	Not economically disadvantaged	416	52.7
	Economically disadvantaged	374	47.3
	Total	790	100
STEM (*n*= 52)	Not economically disadvantaged	35	67.3
	Economically disadvantaged	17	32.7
	Total	52	100

Socioeconomic status (SES) disaggregated by STEM participation for 2013-2014

	SES	Frequency	Percent
Gen. Ed. (*n*= 1179)	Not economically disadvantaged	634	53.8
	Economically disadvantaged	545	46.2
	Total	1179	100
STEM (*n*= 74)	Not economically disadvantaged	49	66.2
	Economically disadvantaged	25	33.8
	Total	74	100

Socioeconomic status (SES) disaggregated by STEM participation for 2014-2015

	SES	Frequency	Percent
Gen. Ed. (*n*= 1140)	Not economically disadvantaged	640	56.1
	Economically disadvantaged	500	43.9
	Total	1140	100
STEM (*n*= 82)	Not economically disadvantaged	57	69.5
	Economically disadvantaged	25	30.5
	Total	82	100

Socioeconomic status (SES) disaggregated by STEM participation for 2015-2016

	SES	Frequency	Percent
Gen. Ed. (n= 1072)	Not economically disadvantaged	656	61.2
	Economically disadvantaged	416	38.8
	Total	1072	100
STEM (*n*= 81)	Not economically disadvantaged	57	70.4
	Economically disadvantaged	24	29.6
	Total	81	100

Socioeconomic status (SES) disaggregated by STEM participation for 2016-2017

	SES	Frequency	Percent
Gen. Ed. (*n*= 704)	Not economically disadvantaged	420	59.7
	Economically disadvantaged	284	40.3
	Total	704	100
STEM (*n*= 63)	Not economically disadvantaged	39	61.9
	Economically disadvantaged	24	38.1
	Total	63	100

Socioeconomic status (SES) disaggregated by STEM participation for 2017-2018

	SES	Frequency	Percent
Gen. Ed. (*n*= 572)	Not economically disadvantaged	348	60.8
	Economically disadvantaged	224	39.2
	Total	572	100
STEM (*n*= 49)	Not economically disadvantaged	28	57.1
	Economically disadvantaged	21	42.9
	Total	49	100

Socioeconomic status (SES) disaggregated by STEM participation for 2018-2019

	SES	Frequency	Percent
Gen. Ed. (*n*= 660)	Not economically disadvantaged	413	62.6
	Economically disadvantaged	247	37.4
	Total	600	100
STEM (*n*= 63)	Not economically disadvantaged	48	76.2
	Economically disadvantaged	15	23.8
	Total	63	100

Appendix C. Descriptive Statistics for Attendance

Descriptive statistics for student attendance in the 2011-2012 school year

	Mean	SD	Min.	Max.	Skew.	Kurt.
Gen. Ed. (*n*=384)	.9569	.0472	.60	1.00	-3.33	18.21
STEM (*n*=21)	.9658	.0192	.94	.99	-.18	-1.43

Descriptive statistics for student attendance in the 2012-2013 school year

	Mean	SD	Min.	Max.	Skew.	Kurt.
Gen. Ed. (*n*= 790)	.9610	.0397	.65	1.00	-2.60	12.31
STEM (*n*= 52)	.9644	.0332	.85	1.00	-1.52	2.31

Descriptive statistics for student attendance in the 2013-2014 school year

	Mean	SD	Min.	Max.	Skew.	Kurt.
Gen. Ed. (*n*= 1179)	.9584	.0425	.71	1.00	-2.98	15.59
STEM (*n*= 74)	.9612	.9612	.85	1.00	-1.39	2.33

Descriptive statistics for student attendance in the 2014-2015 school year

	Mean	SD	Min.	Max.	Skew.	Kurt.
Gen. Ed. (*n*= 1075)	.9576	.0480	.60	1.00	-2.64	10.51
STEM (*n*=71)	.9675	.0447	.70	1.00	-3.72	18.11

Descriptive statistics for student attendance in the 2015-2016 school year

	Mean	SD	Min.	Max.	Skew.	Kurt.
Gen. Ed. (*n*=1008)	.9615	.0405	.63	1.00	-2.38	10.26
STEM (*n*= 73)	.9776	.0238	.89	1.00	-1.53	2.17

Descriptive statistics for student attendance in the 2016-2017 school year

	Mean	SD	Min.	Max.	Skew.	Kurt.
Gen. Ed. (*n*=617)	.9601	.0422	.64	1.00	-2.06	7.17
STEM (*n*=52)	.9531	.0625	.70	1.00	-2.41	6.03

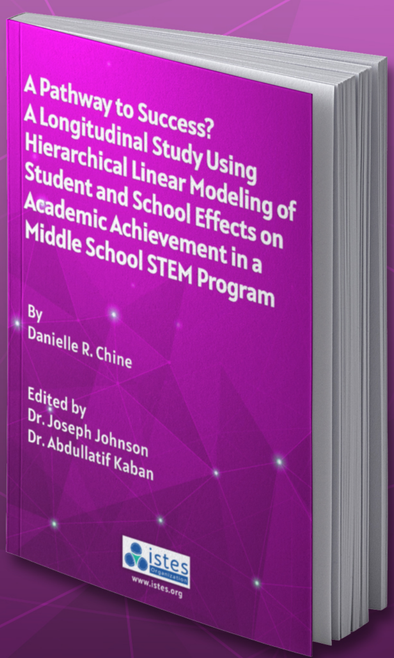
Descriptive statistics for student attendance in the 2017-2018 school year

	Mean	SD	Min.	Max.	Skew.	Kurt.
Gen. Ed. (*n*= 554)	.9573	.0421	.63	1.00	-1.88	7.01
STEM (*n*= 47)	.9600	.0580	.70	1.00	.0580	9.87

Descriptive statistics for student attendance in the 2018-2019 school year

	Mean	SD	Min.	Max.	Skew.	Kurt.
Gen. Ed. (*n*= 578)	.9527	.0490	.44	1.00	-3.91	28.06
STEM (*n*= 45)	.9658	.0314	.87	1.00	-1.12	1.04

This study discusses the effectiveness of a science, technology, engineering, and math (STEM) program spanning grades six through eight in a traditional, urban school district located in Northeastern Ohio. The history and expressed need for STEM education within post-steel producing and economically depressed regions are discussed. Important factors describing STEM programming such as curriculum, standards, content delivery, integration, and aspects of implementation are described. This longitudinal study reports Ohio State Test (OST) scores along with the demographic factors of gender, socioeconomic status, student race, and attendance rate to determine the impact of STEM programming. The use of multilevel, statistical analyses through hierarchical linear modeling (HLM) determined integrated STEM had a significant, positive effect on student achievement in both math and science and an even stronger impact isolating science achievement by itself. The predictive results of HLM analysis determined STEM students scored significantly higher on the OST in science and math combined scoring 31.8 points higher on average and 38.2 points higher in science compared to their general education peers. No interaction effects were determined between STEM participation and gender, socioeconomic status, student race, and attendance rate. This research has powerful implications for educational leaders as they need to be aware of the impact integrated STEM programming and project-based learning (PBL) has on student achievement. The results indicate that integrated STEM programming in middle school has a positive effect on student achievement indicating it is indeed a pathway to success.



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