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Random Acts of STEM: A systematic review of local k-12 school division STEM experiences in Virginia

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Chapter 1: Introduction

Science, technology, engineering, and math (STEM) education is a comprehensive reform-oriented movement in the fields of science, technology, engineering, and mathematics that pursues to cultivate a STEM-skilled labor force as well as a STEM-cultured community to enhance the nation's competitiveness in the international economy (Briggs, 2017). Progressively, descriptions of STEM further encompass reference to an interdisciplinary technique to cultivate a deeper comprehension of every subject via an emphasis on the interconnected nature of STEM. Other descriptions of STEM learning include those that view it as a nontraditional system of education, which transforms students from learning rote processes, pieces of the phenomenon, and discrete bits to examining and critiquing the interconnected aspects of the real society (English, 2016). Although there is an emerging necessity to consider STEM disciplines collectively, more typically, the four subjects are handled distinctively, and mathematics and science form the basis of most evaluations while engineering and technological areas are disregarded. The Virginia Department of Education (VDOE) coordinates with the office of the governor, the Virginia Department of Health, and other state organizations to ensure that communities and schools have the updated resources and information concerning all aspects of education, including STEM learning (Bryan & Guzey, 2020). Nonetheless, there is insufficient literature on the implementation and effectiveness of STEM education in Virginia schools. Additionally, the recent report from the Virginia STEM Commission acknowledged varied STEM awareness across demographic groups and regions. The intention of this research was to evaluate the local STEM policy and practice of Virginia K-12 school divisions.

Statement of the Problem

It is not known how successfully or effectively K-12 school divisions in Virginia implement STEM education policy. Further, while school divisions in Virginia have differing STEM education descriptions, there is a lack of an inclusive assessment of the general policy language. This study aimed to collect, research, and analyze local school division STEM policy in Virginia. The researcher's curiosity about the opportunities and different experiences that have emerged in school localities comes from advocacy work around education funding and a professional career teaching in a STEM field. The varied nature of STEM courses and experiences is of interest to many researchers, policymakers, advocates, and practitioners. Business, industry, higher education, and nonprofits, along with other stakeholders, are working in various capacities to improve student outcomes and to increase participation in STEM fields where there is large workforce opportunity.

The number of students choosing STEM career fields is not meeting demand, and performance is on the decline (Jang, 2016). Changing attitudes and behavior is challenging. STEM education access can be expanded to solve the existing diversity issues with regard to gender, race, disability, and socioeconomic status in the education system. The existing STEM policy and practice are influenced by both institutions and stakeholders. Therefore, this study was conceptualized from the theory of change. The NSF describes a model for the theory of change that links one's desired long-term outcomes to medium and short-term outcomes and specific activities. Theories of change are often developed using a backwards analysis and are project explicit (Reinholz, 2020). Change theories represent theoretical and empirically grounded knowledge about how change occurs and goes beyond one specific project. Using the idea of distinguishing between change theory on the macro level and the theory of change on the micro level, the goal of summarizing the existing STEM landscape in order to assess what specific activities and interventions would most impact short, medium, and long-term outcomes in Virginia STEM education.

Advocates in STEM fields might argue that the importance of creating solid policy is to ensure that not only Virginia, but the entire United States achieves future success through cutting edge technologies. Additionally, improving the welfare and decision-making ability for all citizens is an important goal of expanding STEM education access (Widya, 2019). Policymakers, advocates, and educators need common language, shared definitions, and intentional strategies for both increasing the numbers in the STEM pipeline and ensuring students' experience is aligned with the future workforce needs. On July 17, 2019, Virginia's Governor, Ralph Northam, signed Executive Order 36 to establish the Virginia STEM Education Commission to pull together stakeholders with a focus on aligning STEM education efforts. When specifically considering the Commonwealth of Virginia, the Commission noted there were many opportunities to be engaged in STEM, but the opportunities were not accessible to all (Virginia STEM Commission, 2020). There is a lack of sufficient summative data to help understand the status of STEM.

Most current studies on K-12 education focus on the areas of science and mathematics but disregard the fields of engineering and technology. The rift is even wider when trying to find research that specifically addresses the teaching of STEM with intentional integration of the specific disciplines. The teaching of STEM is still largely in isolation of each of the disciplines (Holmlund et al., 2018; Honey et al., 2014; Ramli & Awang, 2020; Utley et al., 2019). A lack of adequate summative data and research formed the gap that this study aimed to fill by examining the Commonwealth as a whole and collecting evidence of the status of STEM education in

Virginia. It is only with recent, accurate, and summative descriptions of the existing political and curricular landscape that newly formed commissions, coalitions, and education advocates can make the most appropriate recommendations to decision makers. Resources are limited, and it is sensible to allocate these resources to activities that are informed with meaningful change and aligned with short, medium, and long-term goals.

The Rationale for the Study of Problem

The VDOE (2020) asserted that STEM education encompasses realistic instruction experiences for all learners with an applied and interdisciplinary technique where all disciplines link in sophisticated connections. In the contemporary economy, issues are not solved in isolation of a precise field but are solved via multiple perspectives and techniques. A solid STEM educational foundation aids to prepare learners for the future. This is achieved through intentional focus on logical, quantitative, innovative, and collaborative evaluation based on a strong comprehension of the interdisciplinary nature of the four concerned disciplines, encompassing mathematics, engineering, technology, and science (VDOE, 2020). In recent times, beliefs regarding the aim of STEM education have shifted. Customarily, STEM learning has stressed establishing a pipeline of learners whose academic backgrounds prepare them for a STEM-precise labor force. Currently, the focus of STEM education is on establishing STEM-literate people crucial for success in any occupation in the 21st century. As there is no clear picture of how STEM education policy is implemented in Virginia local schools, the collection and examination of local STEM plans, policy, and current practices would ultimately add to the body of knowledge and create opportunities to improve. There was a need to address this gap regarding STEM policy in general and whether it is an accurate reflection of current practice (Franco & Patel, 2018). The move is especially needed in the wake of the demands of changing standards, curriculum, and political landscapes, alongside the additional immediate needs of the new technological workforce.

Virginia students need intentional, vertically aligned, student-centered plans which are designed to prepare them for a rapidly changing world. Researchers, policymakers, and educational leaders need this type of summative data to address the disparities that exist among local divisions. Virginia must identify obstacles and opportunities to build the STEM pipeline to fill STEM jobs. Chmura Economics and Analytics estimated STEM jobs to grow 18% in Virginia by 2024 (Mickle, 2020), which has led Virginia to be identified as a successful STEM career hub. Due to the huge demand for STEM fields and jobs in Virginia, middle and high school learners are encouraged to pursue STEM-related occupations. The VDOE reported that the STEM cluster hired nearly 67,900 Virginians in 2016 and is anticipated to hire an additional 8,100 Virginia employees by 2026, to bring the sum to approximately 76,000 workers. If achieved, this will represent a 12% progression over the decade, which is more than the projected national average growth of 8% in all careers in the STEM cluster (VDOE, 2020). The precise STEM-related careers obtainable in Virginia comprise aerospace engineers, nuclear engineers, environmental scientists and specialists, industrial engineers, architectural and engineering managers, electronic engineers except for computers, social scientists and associated employees, electrical engineers, and mechanical engineers (VDOE, 2020).

Partnerships and coalitions that are working on STEM initiatives need a clear picture of what is happening in Virginia to make progress based on reality rather than assumptions (STEM Ecosystems, 2019; Weld, 2017). Advocates argue that multi-sector partnerships at state, regional, and local levels are basic for the effectiveness of fundamental STEM literacy and labor force growth, particularly in rural areas in Virginia (Rural Virginia Initiative, 2018). The Virginia

Economic Development Partnership (VEDP) plan from 2017 included the statement that "Virginia is not producing enough graduates in computer science and related fields to keep up with the talent needs of the technology sector." At the national level, partnerships are yielding positive results for stakeholders, when partnerships, such as political ones, are started centered on necessities, commitment, and evidence of payback on capitalization. Magliaro and Ernst (2018) and Sondergeld et al. (2016) found that statewide STEM alliances composed of regional centers to support and coordinate STEM experiences are manifesting improved STEM and STEM profession sensitivity, sector involvement, preparation of learners, and prospects for labor force growth. The regional centers aid in undertaking assessments of activity for continuous enhancement, facilitate resource sharing, help in initiation and support of alliances, and stimulate communication via sharing of information. At the local level, alliances that are oriented on necessities as well as mutual language and vision have led to a remarkable efficiency in meeting the association objectives and prolonging the permanency of the partnerships (Zinth & Goetz, 2016).

The Commonwealth of Virginia had expressed the commitment to fill the expected 150,000 additional STEM jobs over the next 5 years with the creation of the STEM Education Commission (Exec. Order No. 36, 2019). Advocacy and policy efforts may be enhanced if data exist to indicate student success in K-12 STEM that lead to a highly skilled workforce. Efforts to replicate successful implementation of STEM on a more regional or state level would also benefit from summary data and comparison across the Commonwealth. However, the more recent impacts of the COVID-19 pandemic on the economy and infrastructure have not been factored into the equation regarding access to high-quality STEM education in Virginia's schools post pandemic. The answers to these questions will likely only become more necessary as the impacts of the pandemic are mitigated for future generations. This study was conducted in the middle of the COVID-19 pandemic, while distance learning barriers existed in education. These were not normal school years, but it may be beneficial that many more school divisions were communicating their activities through their websites. COVID-19 impacted this study and created interruptions and barriers in terms of the activities school divisions offered and what was available to students. A clear definition of the purpose of STEM education in Virginia may also drive the work done at the local level. According to the VDOE website, STEM education was being “refocused,” and STEM literate citizens are necessary for success in any 21st-century professions (VDOE, 2020).

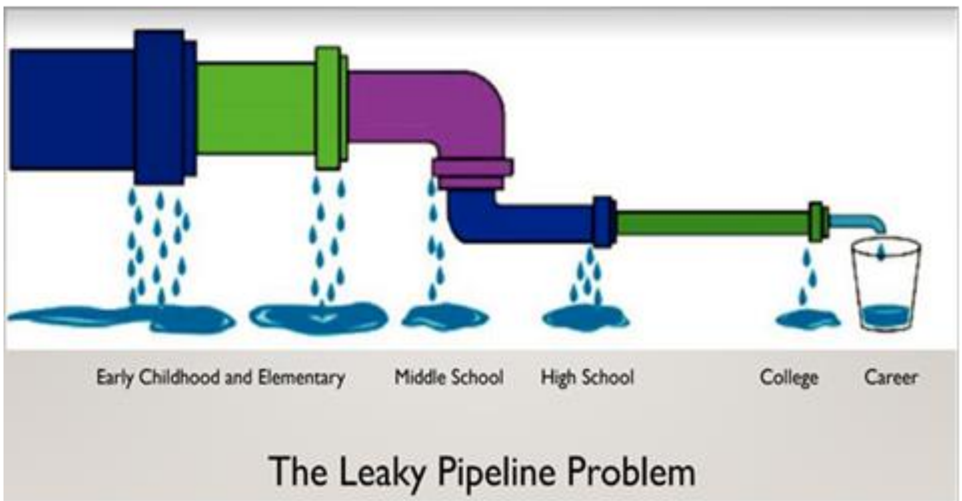
There is a need to address the necessity for STEM in Career and Technical Education (CTE) contexts versus the historical route where students are pressured to take advanced coursework that often lacks practical application (Council, 2011; Franco & Patel, 2018a; Jang, 2016; Martín-Páez et al., 2019). There may be tension between these two academic fields based on how they are perceived by the community (Jang, 2016). Tensions also exist between higher education and industry, which requires immediate skilled students to enter the workforce. Business and industry are recruiting high school students to fill the demand, and some are aiding in obtaining additional training and degrees. School division staffing is an issue as the teacher shortage reaches crisis levels, but the need for someone to manage these tensions and transitions to work base learning is also necessary for implementation success (Virginia STEM Education Commission, 2020). The STEM labor force pipeline sub-committee, part of the VA STEM commission, also noted that the skill pipelines for instructors with training, experience, and knowledge are disjointed and shallow with the industrial needs and the requirements of the 21st-century workforce. The board identified two key obstacles that are hindering the determinations of establishing a solid STEM education experience for all learners in Virginia. The first obstacle is that the lack of prospects, resources, and pertinent competence among various stakeholder clusters has led to an incoherent plan to hire, sustain, and progress highly qualified STEM educators. The second barrier is the lack of state legislation and policy, which alters obstacles between the PreK-20 system and sector to establish inventive groupings to stimulate curriculum growth and access to STEM-associated occupation prospects (VDOE, 2020).

An emerging trend in STEM education is moving science, technology, engineering, and mathematics out of their unique silos and integrating them to facilitate deeper learning (Li et al., 2020). One aspect that makes organizing existing research on STEM challenging is that they are often discussed in their silos and not as a collective field (Council, 2011; Franco & Patel, 2018a; Honey et al., 2014; Widya et al., 2019). At the same time, there is an emerging trend to integrate STEM as well as the standards movement that led to testing content in a much-defined way that does not value integration of the disciplines. One of the barriers to successful STEM implementation is that the traditional school structure and schedule does not always allow for the integration of the content areas (Margot & Kettler, 2019; Martín-Páez et al., 2019). An analysis of local school divisions to examine which of these is prominent in practice will be useful to both researchers and practitioners. From the evaluation, researchers may be in a better position to recommend the most effective approaches to integrate STEM education fields into an interdisciplinary program. Practitioners such as teachers and school administrators determine the most suitable techniques for actively engaging in the instruction of interdisciplinary STEM education.

Some feel the key component with the STEM initiative is not solely to increase the number of STEM workers but to also address the issue of diversity in STEM fields (Bullock, 2017). It stands to reason that expanding the number of students who have access to high-quality STEM education will naturally increase the numbers in the STEM career pipeline. Researchers have also documented that due to socioeconomic structures, gender bias, and racial inequities, there are untapped resources that could explain the leaky STEM pipeline (Crabtree et al., 2019; Dasgupta & Stout, 2014; Fayer et al., 2017; Pike & Robbins, 2019).

Figure 1

Leaky Pipeline



Women leak out of the STEM careers without any data showing why these leaks occur. Because this is a widespread issue, assumptions are often made that this is caused by gaps in the system. There are two vast areas to address regarding diversity: gender and minority populations. Additionally, what research says about best practices in increasing student diversity in STEM fields should be compared with the reality of implementation at the school level. An analysis regarding how access to courses compares with future success in college is necessary (Flores et al., 2017; Xu, 2015). Data can be collected regarding who participates in STEM courses and activities and compared to that of the general student population. Some districts have public documents that state the number of students in courses, which may also be used to determine the capacity of the division to offer STEM courses. Gaps regarding gender, minority, and students with disabilities (SWD) exist in STEM courses and will likely need to be reviewed and separated into categories for STEM policy and practice analysis as well as discussion in the future.

Another area of attention for the research problem around access is the type of STEM experiences that exist in the local district. There is a need to evaluate at the local level whether schools adopt specialized systems reserved for a few learners or STEM-for-ALL techniques in course offerings. The other area of concern is to investigate whether the local schools offer STEM education mainly after school or via extracurricular programs. Much research has addressed the STEM experiences that can be gained outside of the typical educational environment (Hurst et al., 2019).

Statement of Purpose

The purpose of the current study was to investigate the local school division STEM policy and practice in Virginia. The initial aim of this research was to determine whether the school divisions in Virginia have published definitions of STEM education. For the divisions that have clearly defined STEM education, the subsequent assessment was based on the precise STEM education definition each has implemented. Along with a search to determine what locales have in their defined plans is a broader search for evidence regarding whether that definition is integrated among the disciplines, embedded in the school day, and serving a diverse set of learners. There is inadequate literature on how successful or effective K-12 schools in Virginia have implemented the local STEM education policy. The immense demand for STEM fields and careers in Virginia is significant to encourage middle and high school learners to pursue STEM-related occupations. The current study helped to illuminate what is happening in Virginia. Most current studies on K-12 education stress the areas of science and mathematics but disregard the fields of engineering and technology (Holmlund et al., 2018; Honey et al., 2014; Ramli & Awang, 2020; Utley et al., 2019).

Analyses of state-by-state STEM education plans exist; a similar format can be useful at the local level (Carmichael, 2017). The first step of the analysis was to determine if the local school division has an existing STEM plan. If a plan existed, then the researcher examined the plan more closely to determine whether the division defines STEM education in their plan. Other documents, such as the division's programs of study offerings, strategic plans, and STEM-focused schools, can usually be found on division websites. The other areas for further investigation were within school budgets and policy documents.

Positionality

The desire to examine this topic grew out of discussions and practical experience the researcher had when working with multiple school divisions and trying to define their STEM footprint. Educators who were involved in STEM had a difficult time identifying activities across their own schools and the division. Many educators were seeking professional development and searching for high quality STEM experiences for their students. The researcher was also employed at a nonprofit curriculum provider, Project Lead the Way (PLTW). Some of the school divisions in Virginia use this curriculum and are familiar with the researcher through the program. These existing relationships could impact the research in that some participants specifically mentioned their use of the PLTW program during their interview. Not all the participants were familiar with the research or with the PLTW programs.

The researcher was also a former mathematics teacher and a math specialist, and thus had prior knowledge of some school divisions' STEM programming. The researcher had delivered professional development to elementary and middle school teachers in the math, science, and engineering design process. The researcher spent a period of time as an educator at the MathScience Innovation Center, working with 12 school divisions in the Richmond area. During this time, the researcher took integrated STEM lessons out into schools and worked with educators on how to increase their efficacy in delivering integrated STEM lessons. It is important to note these experiences have helped to shape the lens through which the researcher envisioned the existing STEM environment. The experience of traveling to multiple schools in several different school divisions to improve STEM experiences for students allowed for a unique perspective regarding resources and capacity. Noticing the differing degree of resources and access to STEM lessons created a desire to better understand the larger STEM education experience in Virginia.

Historical Information and Influence

A review of literature to ground the research within the historical context and changes that have influenced the U.S. national education system. The desire to compete on the global stage has grown more polarizing and political during recent years. The National Science Foundation (NSF) 1950, *A Nation at Risk* 1983, The National Science and Technology Council (NSTC) 1993, No Child Left Behind (NCLB) 2002, Race to the Top (RTTT) 2009, STEM ecosystems 2015, and Committee on STEM Education (CoSTEM) 2010 all discuss the need for high-quality STEM education for the United States to be a global leader (Chism, 2015; Committee on STEM Education, 2018a; Levin, 1984; Paige et al., 2002a). Each of these policy initiatives is nested in the changing social structures of schooling and society. Further, each initiative has contributed significantly to the status of STEM education. According to the National Science Foundation (1994), two historical events – the Great Depression and World War II – expanded government agencies and services at the federal level. During this time, a

New Deal Senator from West Virginia, Harry Kilgore, introduced legislation that suggested the creation of what would ultimately be known as the National Science Foundation (NSF). President Roosevelt then requested a report on how the nation should support science in the new postwar period (Mazuzan, 1994). Differing ideas about science education have long been in existence in the United States. The debate of the 1940s surrounding the economy, health, energy, and national security are not unlike the debates that occur currently in policy arenas. It is useful to identify themes from decades ago that are still topics in current STEM policy discussions.

The roots of some STEM education initiatives can be traced in the Sputnik Era that “launched” a competitive spark for the United States to become leaders in STEM. The appropriations for the NSF after Sputnik tripled, and 10 years later were more than 10 times its pre-Sputnik budget. In 1958, the National Defense Education Act increased the commitment of the federal government to science education (Chism, 2015). It was further during the 1950s that the landmark case of *Brown v. Board of Education* declared the practice of racial segregation of public schools unconstitutional. This marked a time of great technological and social change. Parallels could be drawn to the launch of cyber-attacks as the next race to dominate the global data-based security threat.

In the 1970s and 1980s, the world witnessed the Space Shuttle launch, the emergence of personal computers, and the introduction of the first cell phone. In 1972, Title IX of the Education Amendments Act prohibited public schools from discriminating based on sex. In 1980, Congress established the cabinet-level U.S. Department of Education position. In 1983, the report titled *A Nation at Risk* was released with a declaration portraying the world as “one global village” (Denning, 1983). The aim of the report was further to include the religious, ethical, and intellectual strengths of Americans that combine the fabric of the world. The report also signified that Americans must understand that persons lacking the levels of training, literacy, and skills important to the new generation would be excluded from material rewards and opportunities to engage entirely in the U.S. national lifestyle (Wilgus, 2019). Wilgus (2019) also asserted that a high degree of mutual education is important to a democratic and free society as well as in fostering common culture, particularly in a nation which prides itself on individual freedom and pluralism.

In 1987, the NSF announced an award of the NSFNET Cooperative Agreement to Merit, IBM, and MCI which is the foundation for the Internet. In 1990, NSF announced the first planning grants for the Alliances for Minority Participation Program (AMPP) to increase the number of minority scientists and engineers. In 1998, the first female director of the NSF, Dr. Rita R. Colwell, was appointed. Each of these actions demonstrates how society continued to change along with the emphasis on science education, but the 2000s brought attention to the dire need for U.S. students to increase their proficiency in STEM fields, which were growing at an unprecedented rate. The acronym STEM, representing Science, Technology, Engineering, and Mathematics, was introduced by administrators at the NSF. Previously, the acronym SMET had been used when describing career fields in those disciplines or a curriculum that integrated knowledge and skills from those fields. Most investigators credit the acronym change to the increased dialogue around STEM because it was easily identified (Mazuzan, 1994). Once the acronym gained recognition, many argued that it should be STEAM, with the “A” being for the Arts, or STREAM, with the “R” being for reading, Legislatures have also used STEM-H with the “H” being for Health (Perignat & Katz-Buonincontro, 2019).

Education reform efforts were also in full swing with the inception of No Child Left Behind, (NCLB) ushering in standards-based testing reforms and sanctions against schools that were not meeting adequate yearly progress (AYP) goals (Paige et al., 2002b). In 2009, the Council of Chief State School Officers and the National Governors Association launched the Common Core State Standards Initiative, which emphasized that students' learning could be consistent and stationary across the nation. This was coupled with accountability and school funding being suddenly tied to a school's test scores. Since 2010, 46 of the 50 U.S. states and the District of Columbia have been members of the Common Core State Standards (Mariana, 2012). However, Virginia is not a member of the Common Core States, but it has developed consistent standards of learning (SOLs) for all the students across the Commonwealth. The standards movement also changed what science education would look like with the creation of the Next Generation Science Standards (NGSS, 2013). A 2009 report published by the Carnegie Corporation entitled "The Opportunity Equation: Transforming Mathematics and Science Education for the Global Economy," included the statement that the commission "urges the United States to mobilize for excellence in mathematics and science education so that all students not just a select few, or those fortunate enough to attend certain schools achieve much higher levels of math and science learning" (Bose, 2011, p. 9). In 2011, the National Research Council publication entitled, "Successful K-12 Stem Education, Identifying Effective Approaches in Science, Technology, Engineering, and Mathematics," furthered the work of investigating the status of STEM education. The goal of this was to provide information to leaders at local, state, and national levels to use to make decisions about STEM education (Council, 2011). The report noted that the bulk of the research was in the areas of math and science, as research in the areas of technology and engineering was not standard in K-12 education.

The Committee on STEM Education (2018) created a report titled "Charting a Course for Success: America's Strategy for STEM Education" with the purpose of outlining the government's 5-year strategic plan for STEM education. The report suggested that in the last 25 years, STEM education has effectively transformed from a convenient grouping of four overlapping academic fields to a more cohesive information foundation and skill cluster paramount for the 21st-century economy (Lai, 2018). The report further noted that the ideal STEM education offers an interdisciplinary technique of learning, where rigorous academic notions are combined with real-world applications and learners adopt STEM in scenarios which make links between schools, society, careers, and the general world (Lai, 2018). The report further stated that this is primarily a state and local responsibility, further demonstrating the need to capture a more defined picture of what is happening at the local level. President Barack Obama further revived the concept of STEM education by arguing that the United States would only prosper in the 21st century when children are provided with better education (Honig & Weaver, 2019). One of the ways that President Obama suggested offering an improved education in schools is the incorporation of STEM education. Under President Donald Trump the U.S. Space Force was established in December of 2019 when the National Defense Authorization Act was signed into law. This was the first new branch of the armed services in 73 years. This also demonstrated the importance of STEM fields to national security.

Further literature exists on the workforce development and career opportunities of STEM fields as being the purpose to increase the numbers in the STEM pipeline. As the Smithsonian Science Education Center described "The STEM Imperative," on their website, STEM careers grew at a rate of three times the rate of non-STEM jobs between 2000 and 2010. It is projected that 2.4 million STEM jobs go unfilled (Smithsonian, 2018). Additionally, minorities and females are underrepresented in STEM fields. Just 2.2% of Latinos, 2.7% of African Americans, and 3.3 % of Native Americans and Alaska Natives have a degree in the STEM fields. According to the Education Commission of the States website, the United States needs more STEM talent to meet the demand. It is estimated that between 2017 and 2027, STEM jobs in the United States will increase by 13%. Business and Industry cannot find the talent that they need to remain competitive in a global economy (Utley et al., 2019). Out of 100 STEM occupations, 93% had wages above the national average according to the U.S. Bureau of Labor Statistics. With these statistics, it is imperative that officials of K-12 schooling consider the future careers of its students and address whether they are doing enough to create success in STEM fields. It is with those contexts and a lack of collective evidence that the researcher ought to collect and summarize data in order to create a picture of the existing STEM environment within local school divisions in Virginia.

Research Questions

The following research questions guided the current study.

RQ1: Does the local school division have a definition of STEM education?

RQ2: If a school division has a definition of STEM education, does the policy employ the disciplinary definition or the integrated description of STEM education?

RQ3: Is there evidence in the school division that the STEM education activities are embedded in the school curriculum or part of the after school and extracurricular activities?

RQ4: Does the school division have a STEM for ALL approach or strategy to increase representation of gender, minorities, or students with disabilities in STEM?

Methodology

The research methodology that was incorporated in this study was exploratory mixed methods, which encompasses both qualitative and quantitative approaches as well as the content analysis approach. Quantitative content analysis is an evaluation device employed to find the presence of specific concepts, themes, and words within quantitative information, such as text data (Xie et al., 2019). The methodology is principally used to assess policy topics through documents, newspaper articles, technical reports, and expert interviews. The population for the current study included all the school divisions in Virginia. No sampling formula or procedure was required because the entire population of school divisions in Virginia was included as the sample for this study. The qualitative data analysis and interviews conducted were based on a sample of the larger population. The reason for selecting this population is because the goal of the research was to examine and summarize the local school division STEM education experiences in Virginia, but it was not likely that all school divisions would voluntarily contribute to the interview process.

The primary sources for collecting the essential information were the school division websites and a secondary sampling of follow-up interviews with STEM personnel at the school division level who volunteered to be interviewed. All websites for the school divisions were accessible from the VDOE site. Searches were made from the school division websites and general Internet browsers. From the divisions' websites, the phrases that were applied for searching comprised "STEM," "STEM education," "STEM Plan," and "STEM education policy," STEAM," "STREAM" and "STEM-H." The concept behind these searches to locate documents and materials that would help determine the implementation types of STEM education in the school divisions in Virginia. The secondary stage included interviews with school division leaders familiar with the STEM experiences for the division. Great effort was taken to recruit interviewees within different size divisions as well as differing geographic regions of the Commonwealth. This was important because different geographical regions from the state represent the varied communities, businesses, and industry in Virginia. It was difficult to obtain volunteers for the interviews. Ultimately, five participants were interviewed representing four different superintendent regions around Virginia.

Summary

It is not known how productively or efficiently K-12 school divisions in Virginia have implemented STEM education. The literature background further discloses that while different school divisions in Virginia have STEM education descriptions, there is a lack of an inclusive assessment of the STEM landscape in Virginia. The research aimed to examine the local school division STEM initiatives in Virginia. The initial purpose of the study was to determine whether the school divisions in Virginia have definitions of STEM education. For the divisions that have described STEM education, the following valuation was based on the precise STEM education definition each has implemented. There has been an examination of state-by-state STEM education strategies (Carmichael, 2017). The research methodology used was the exploratory mixed method that encompasses both qualitative and quantitative content analysis approaches. The population for the study included all 132 school divisions in Virginia with follow-up interviews with STEM personnel in five school divisions. Chapter 2 will provide an in-depth and comprehensive literature review based on the study concepts and research questions.

Chapter 2: Review of the Literature

This chapter contains a discussion of existing literature surrounding Science, Technology, Engineering, and Mathematics (STEM) education, STEM policies, and other related topics. For this review of the literature, the search strategy involved a comprehensive search in various databases, using search terms individually and in combination with Boolean terms such as “and,” “or,” and “not.” The search terms used were *STEM, science, technology*, *engineering*, *mathematics, interdisciplinary, integrated, curriculum, state policies, state programs, STEM schools*, *STEM academies*, *engineering design*, *diversity*, *inclusion*, *urban*, *rural*, *school division*, *school district*, and *school change.* The databases used included ResearchGate, EBSCOhost, ERIC, Springer, Elsevier, and Google Scholar. From the results of these searches, 77 were included in the final review, 71 (92.2%) of which comprised recent works from 2017 onwards, and six (7.8%) of which were important seminal works from 2016 and earlier.

Overview

The siloed nature of STEM education within many schools in the United States presents an important issue in both research and practice, as these siloes or disciplines are often taught and discussed separately (Holmlund et al., 2018; Honey et al., 2014; Ramli & Awang, 2020; Utley, 2019). Recently, more attention has been given to an integration of STEM, making it more relevant to real-world settings and to meet the necessary skills for the 21st-century individual (Honey et al., 2014; Widya et al., 2019). Despite this focus on STEM integration, there remains a dearth of evidence regarding how integrated STEM is being perceived and taught, especially in the state level and in the context of locales. The purpose of the present study was to collect, research, and analyze local school division STEM documents in Virginia. A summative statement regarding the existing strategies for STEM in Virginia did not exist prior to this study. This study aimed to first address whether each division has a specific definition of STEM in their local division. It also sought to address whether they are intentional about integrating the STEM disciplines and increasing diversity in STEM, and if it is embedded in the school day or often part of the extracurricular program. Through the systematic analysis of school divisions' websites along with a sample of follow-up interviews, the study provided a snapshot of the current reality of STEM education in Virginia. This is necessary to advocate successfully for any statewide STEM initiatives, funding, or legislation. Most of what is known is anecdotal, limited by geographical region, and has led to the random acts of STEM experiences in the Commonwealth.

The topic of STEM education and policies are complex and span several areas of discussion, such as unique discipline approaches, diversity, equity, professional development, K-12 alignment, and even location structures. These factors all have some bearing on how policymakers and school leaders design their STEM programs and curricula. The following sections include in-depth discussions of the review of relevant literature covering the many interrelated topics that factor into STEM education. Changes to STEM education occur within a complex system and change agents must consider factors that influence the current context (Reinholz, 2020). Policymakers should consider the various gaps in the STEM fields to establish the populations that STEM policies should target. Professional development for educators and local division staffing capacity and funding resources are also important considerations for STEM policy to provide access to high quality STEM education for all. Understanding the essence of these issues helps frame the literature and its relevance to the present study.

Integrated STEM

The integration of STEM in education is a relatively novel idea. Although STEM education has existed for more than a decade, it still lacks a universal definition that brings the four disciplines of STEM together rather than as separate disciplines or in siloes (Carmichael, 2017). The traditional educational setup appears to prevail, as many schools persist in teaching STEM in a siloed manner. Without a standardized definition of STEM, educators continue to take on this traditional view of disciplinary STEM (Ring et al., 2017). Educators may not be fully prepared to teach an integrated form of STEM (Ames et al., 2017). The lack of professional development opportunities for these educators represents another serious issue for STEM education and policy (El-Deghaidy et al., 2017; Park et al., 2017). As the perception of STEM shifts from disciplinary to integrated, policies on professional development should be examined to ensure that educators are well-prepared.

Based on the history and background of STEM discussed in Chapter 1, STEM has undergone much development since the early days of the NSF. Although STEM research has developed considerably over the decades, researchers' perceptions and outlooks regarding STEM education appear to be varied (Li et al., 2020). The lack of a universal standardized definition for STEM education has led to the various understandings of STEM from disciplinary to transdisciplinary (English, 2016). While some might consider a degree or practice in individual disciplines of STEM as part of STEM, others emphasize the need for the integration of these disciplines (Li et al., 2020). Some researchers have focused on individual disciplines, some on a combination of two or more disciplines, and some have even included other disciplines, such as geography and literacy (Franco & Patel, 2018). While these disciplines are all important parts of education and educational research, focusing only on a select few of them makes it difficult to compare and contrast research findings (Franco & Patel, 2018). The variety of these definitions make it difficult for those who are responsible for researching, planning, and implementing STEM education. Even those who work the closest with STEM, such as educators, have difficulty defining STEM education (Carmichael, 2017). A review of existing literature on STEM may provide some insights as to what the various definitions are and how they may be consolidated or standardized for STEM policymaking. The relevance is that when there is not a common understanding or universal language used to describe STEM, it is difficult to communicate what the current conditions are in Virginia.

The simplest perspective regarding STEM is the traditional disciplinary perspective (Carmichael, 2017). Based on this perspective, a focus on any of the four disciplines is already considered as STEM. Students may not be taught about the scientific way of knowledge construction or the engineering process of problem-solving (Widya et al., 2019). Without these processes, the content knowledge taught in classes may seem meaningless, and students may have difficulty retaining them. Furthermore, these subjects are often taught in a siloed manner, separate from each other, without recognizing the potential connectedness between these subjects (Widya et al., 2019). The siloed manner of teaching STEM also leads to unbalanced attention given to certain disciplines (English, 2016). For instance, in the 2014 STEM conference held in Vancouver, 45% of the regular papers presented centered on science, while technology, engineering, and mathematics only comprised 12%, 9%, and 16% of the papers, respectively. Additionally, the main perception of many nations regarding STEM is that it reflects a broad-based scientific literacy. It appears that ideas of STEM education often revolve around the subject of science.

Imbalance in STEM

Researchers have highlighted the lack of focus on engineering in the siloed STEM education. In a study on Saudi Arabian science teachers' perceptions of STEM, El-Deghaidy et al. (2017) noted that engineering was the least discussed discipline within the focus groups. The teachers appeared to have limited knowledge regarding engineering and how to teach it. Furthermore, the teachers appeared to have no clear ideas of how to integrate this discipline with the other disciplines. The teachers perceived that the subjects of science and mathematics were the easiest to integrate (El-Deghaidy et al., 2017). McClure et al. (2017) likewise emphasized the lack of focus in engineering and technology, particularly in early childhood education. In some perceptions of STEM integration, the only indication of the inclusion of engineering was through the use of engineering design as a teaching strategy for the core content subjects of science and mathematics (Margot & Kettler, 2019). Although engineering design appears to be an important and effective tool for teaching, the lack of any other means of integrating engineering into education lowers its value in comparison to the other content subjects.

Even in STEM-focused schools and programs, an engineering focus may still be lacking. Out of eight high-performing inclusive STEM schools in the United States, Peters-Burton and Johnson (2018) reported that three did not offer engineering education. In a study examining a summer educational program for middle and high school students, Schwab et al. (2018) found that the program appeared to be largely focused on science and mathematics. With specialized science subjects such as astronomy and chemistry of food included in the program, it was confounding why no engineering subjects were included. It appears that, in the siloed or disciplinary approach of STEM, engineering is often overlooked, causing imbalance within the STEM disciplines. This finding is troubling considering how engineering design practices and computational thinking are part of the *Science Standards of Learning* and *Computer Science Standards of Learning* by the Virginia Department of Education (2018). Based on the literature above, some institutions may have not yet caught up to these standards. Also, because these computer science standards are not measured on an end-of-course assessment like other standards, it is difficult to know how and where they are addressed in the curriculum.

This imbalance was predominant in early childhood education. The traditional notion about engineering and technology is that these are advanced subjects for the high school level that are not suitable for younger children (Holmlund et al., 2018); however, Gold and Elicker (2020) emphasized how children's play can reflect engineering even at a young age, as they design and build structures with toy blocks and other materials. Through these kinds of play, children can learn about engineering principles, such as problem-focused designs. Engineering learning through constructive play is further strengthened by peer play when children build together. Through communication and teamwork, children can learn to define their goal, such as building a tower; discuss and learn about how to build the tower; formulate a plan; try the plan; test the plan; test possible alternatives; and try these new ideas until they successfully achieve their goal of building a tower. This process is called the engineering design process and is highly valuable in STEM education (Gold & Elicker, 2020). Engineering design in early education may provide valuable foundations that would eventually link with engineering concepts as students progressed (English, 2016). Furthermore, when the engineering design process integrates both science and mathematics concepts situated in real-world problem-solving activities, the students are more engaged (Tougu et al., 2017). As educators face this relatively new subject, strategies such as engineering design should be considered to integrate engineering with the other STEM disciplines. Learning these design skills and applying a child's natural curiosity and creativity at an early age serves to improve a child's interest in STEM fields. One hope of this study was that there would be a collection or sampling of STEM experiences described through the school divisions' websites. These descriptions were important to determine whether they are offered as an embedded part of the curriculum or after school hours.

High Demand Skills

Despite the lack of focus on engineering within STEM education, it remains to be a highly relevant field in society. Examining its relevance in practice, Jang (2016) investigated the necessary skills for the workplace within the 21st century. Jang examined data from the O*NET 18.1, which is the Department of Labor's standardized, job-specific database. The O*NET 18.1 contained data from 9,950 relevant STEM workforce employees and stakeholders, indicating the skills and knowledge they sought in employees. According to the data, STEM-related companies seek individuals with more knowledge of engineering and technology rather than of the natural sciences (Jang, 2016). Fayer et al. (2017) also noted that 19% of employments in STEM comprised engineers, compared to only 4% of mathematical science occupations. In a literature review of STEM articles between 2013 and 2018, Martín-Páez et al. (2019) found that a majority (58%) of studies and interventions on STEM education included some sort of engineering concept, such as the use of engineering design or engineering-based problems. On the contrary, English (2016) stated that engineering was underrepresented in the integrated STEM research. Regardless of these inconsistent statements between Martín-Páez et al. (2019) and English (2016), both sets of researchers agreed that there is a need to bring more engineering practices into the classroom.

While most researchers have agreed on the need to place additional focus on engineering in STEM education, researchers presented differing views on which other field required more attention and further integration in STEM. English (2016) indicated that mathematics was another underrepresented topic in STEM research. Although both science and math were already well-defined areas in education, the common approach is teaching them separately (Holmlund et al., 2018). Baker and Galanti (2017) likewise indicated that mathematics, in particular, is often taught in isolation from the other STEM disciplines, and that the focus of mathematics is mostly on rote skills and memorization.

The discipline of technology in STEM was also cited to be underrepresented in education (Holmlund et al., 2018; McClure et al., 2017). A common misconception regarding the discipline of technology is that it only serves as a tool to enhance science or mathematics learning (Wells, 2019). Within the secondary education setting, greater focus on technology education as a standalone field is often only found in career and technical education (CTE) (Holmlund et al., 2018). The CTE track helps students to cultivate skills to prepare them for the workforce or postsecondary education akin to its precedent, vocational education (Rosen et al., 2018). The former vocational education programs were criticized for being a track that led minority students to low-level occupations with its poor educational quality. Since the 2001 No Child Left Behind Act, such programs were forced to improve and evolve into what is now known as CTE (Rosen et al., 2018). The majority of the science teachers in the study conducted by Holmlund et al. (2018) on STEM omitted technology in their professional development maps, and the few who did include it were teachers who worked closely with it. The lack of focus on technology as a STEM discipline is problematic, as approximately 45% of STEM employment involved computer occupations, and this is projected to increase even more for the next few years (Fayer et al., 2017). Based on existing literature, it appears that STEM education is still highly disciplinary or siloed, showing a lack of integration even in the foundational subjects, such as mathematics. An additional reason for conducting a systemic analysis of local school division policy was to determine where engineering and technology courses fit into the curriculum. I sought to determine whether these were considered as advanced coursework or embedded into career and technical pathways aimed at meeting the needs of the local community workforce.

Integration of STEM Disciplines

The disciplinary or siloed approach to STEM may be growing obsolete in the 21st century. Scholars and researchers have suggested that an integrated or interdisciplinary approach is more suitable for developing 21st century students in preparation for the workforce (Holmlund et al., 2018; Honey et al., 2014; Woods & Hsu, 2019). The integration of STEM would allow students to not only master scientific or mathematical concepts but also to use these concepts in collusion with technology and engineering design to solve real-world problems, making STEM education more relevant (Honey et al., 2014; Woods & Hsu, 2019). One way to distinguish integrated STEM from disciplinary STEM is that integration allows for an outcome that is "greater than the sum of its individual parts" (Martín-Páez et al., 2019, p. 800). In the state of Virginia, a commission for STEM education was established in 2019 to develop a state-wide STEM plan (Exec. Order No. 36, 2019). The commission has since defined STEM as an applied and interdisciplinary system of meaningful learning experiences wherein the disciplines are connected in elaborate relationships to serve all students (Virginia STEM Education Commission, 2020). This definition emphasizes integration in its recognition that real-world problems cannot be solved in isolation of individual disciplines. However, there remains to be a lack of agreement regarding the exact subject areas that constitute STEM (Granovskiy, 2019). As a relatively new approach, more work is needed to properly define and establish integrated STEM as a potential replacement for the traditional disciplinary STEM.

Differing views of how STEM integration should be perceived are present in the literature. Carmichael (2017) cited a four-stage perception of STEM education, wherein the true integration of STEM rested on the final stage. The first stage reflects the traditional disciplinary approach to STEM. The second stage is multidisciplinary, retaining the separate disciplines but teaching them with a common theme. The third stage is interdisciplinary, which involves two or more closely interconnected disciplines. Finally, the fourth stage is transdisciplinary, which also features closely interconnected disciplines with the addition of real-world applications (Carmichael, 2017). El-Deghaidy et al. (2017) presented a similar description, relaying how the boundaries between STEM disciplines blurred as the approach shifted from multidisciplinary to interdisciplinary. Perignat and Katz-Buonincontro (2019) presented an additional approach, the cross-disciplinary approach, which involves focusing on one discipline through the lens of another. It should be noted that these terms have been used interchangeably in the literature, causing confusion as to what is actually being conferred (Gardner, 2017; Honey et al., 2014). Nonetheless, the general idea behind STEM integration is that the disciplines are taught in explicit conjunction with each other, where students can learn to solve real-world problems using concepts from all the disciplines in a student-centered environment (Ring et al., 2017). With this approach to integrated STEM, students learn about content as parts of a problem requiring solutions (Gardner, 2017). This comprehensive definition of integrated STEM appears to capture the majority of the elements presented in various authors' definitions.

Based on the ideas of integration presented above, shifting to an integrated STEM approach from disciplinary or multidisciplinary approaches requires a complete restructuring of the learning system (El-Deghaidy et al., 2017). The traditional practices of teaching core subjects such as science and mathematics as separate disciplines would have to be overhauled. While a complete integration of STEM disciplines is ideal, McClure et al. (2017) indicated that this idealistic perception may be impossible or ineffective. McClure et al. gave the example of trying to integrate the discipline of engineering into life sciences such as biology, which are highly incompatible subjects. Furthermore, they noted that there is scant evidence supporting the notion that total integration of STEM is superior to the other approaches to STEM (McClure et al., 2017). As such, before schools and educational policies undergo a complete overhaul, there is a need to collect and analyze exhaustive evidence on the optimal integration of STEM and how this can be applied to policy. Cases such as these may require a theory of change, which describes an approach for making a change initiative based on explicit assumptions and expectations and subsequently utilizing these assumptions and expectations to plan, implement, and evaluate the change initiative (Reinholz & Andrews, 2020). This approach would allow STEM practitioners and policymakers to properly assess incremental and evidence-based strategies for STEM integration.

Teacher Preparation for Integrated STEM

Another important element of STEM integration is teacher preparation. The traditional disciplinary approach of education has been established through decades of experience, and teachers, who were educated under this traditional approach, may not be prepared to adapt to a changing system (Fraser et al., 2018). The shift in teaching approaches to a real-world and problem-solving context also entails a shift in the teachers’ roles from instructor to facilitator (Gardner, 2017). Furthermore, teachers are used to the traditional setting wherein each teacher is devoted to a single discipline, which may make integration difficult for those who are unfamiliar with the other disciplines (Holmlund et al., 2018). Notably, out of all the public schools in the United States, only 50% offered calculus, and chemistry and physics were not offered in 27%

and 40% of the schools, respectively (Woods & Hsu, 2019), whereas computer science was only taught in 45% of all U.S. high schools (Code Advocacy Coalition, 2019). Therefore, teachers may not be equipped to teach these subjects.

As an example of the need for professional development, Ames et al. (2017) examined the preparedness of Utah science teachers in teaching integrated STEM, particularly with the use of engineering design. They administered a survey to 650 science teachers during the academic year of 2013-2014, which represented a time when state standards incorporating the integrated STEM curriculum was being published. Ames et al. stated that this allowed the data to reflect the actual preparedness of teachers without any professional development. Their results revealed only an average level of teacher preparedness for the integrated curriculum, but it also revealed that teachers generally agreed that such integrated curricula should be utilized. An interesting finding from this report was that physics teachers were the most prepared to teach with the engineering design (Ames et al., 2017). Widya et al. (2019) examined the literature regarding STEM in Saudi Arabia, Malaysia, Korea, and Thailand. They found that teachers generally had vague ideas about integrated STEM but not about how to properly implement it. The authors highlighted the need for professional development to deepen teachers' understanding of integrated STEM and apply evidence-based best practices (Widya et al., 2019). These findings revealed the need for further professional development before fully transitioning into integrated STEM.

Transition Strategies

As schools begin to transition to the integrated approach to STEM, certain strategies may be necessary to help prepare the teachers. Lesseig et al. (2017) recommended a more gradual transition wherein only a certain number of days are dedicated to integrated STEM. Within these

STEM days, an experienced STEM teacher, who may or may not be the students' regular teacher, would come in to teach integrated STEM in lieu of the students' regular disciplinary classes. Allowing for a more gradual transition may also help balance the needs between the exploratory element of integrated STEM and the need to meet grade-level content standards (Lesseig et al., 2017). Integrated STEM also requires a collaborative effort between teachers with various backgrounds and expertise (Gardner, 2017). Constant communication and choreographing integrated STEM lessons would help to ensure proper integration across disciplines.

Co-teaching between a novice and experienced teacher may be beneficial for this transition period as teachers adjust to the integrated STEM approach (Gardner, 2017). The strategy of pairing teachers with STEM coaches was highlighted in Ortmann and Roehrig's (2019) study. They presented a coaching model wherein coaches worked with teachers in planning, writing, and implementing the curricula, as well as having reflective conversations (Ortmann & Roehrig, 2019). Participants in the study by El Nagdi et al. (2018) likewise stated that collaboration and team-teaching were important in integrated STEM education, particularly with a group of teachers with diverse backgrounds. Participants also highlighted the similarities between the teachers' roles and what was expected from students in integrated STEM, as both shared a need for ongoing learning. As such, teachers must continuously seek and test multiple strategies to teach integrated STEM (El Nagdi et al., 2018). Promoting CTE subjects such as engineering, biomedical, or computer science in high school may also help to create more accessible pathways from high school to employment in STEM (Rosen et al., 2018). Transitions are often difficult, especially when one is coming from a system that has been established for decades; however, the strategies presented here may help to ease teachers' transition to integrated STEM.

Fraser et al. (2018) also highlighted the important role of school principals in fostering a culture of STEM integration. Part of their responsibilities as principals was to inspire a vision for STEM, maintain the culture of STEM learning, support their faculty and staff, and continuously evaluate their school's approach to STEM education (Fraser et al., 2018). It may be difficult for principals to cater to these myriad responsibilities when they themselves do not have experiences or have not received any training regarding STEM integration and education (Sterrett et al., 2018). The lack of a clear definition of STEM may also influence how principals lead in their schools. Sterrett et al. (2018) thus sought to examine principals' teaching experience and perspectives regarding teaching, STEM instruction, and the type of feedback they offered to their teachers. In their qualitative study, the sample comprised four principals from acclaimed STEM schools in North Carolina. These principals had diverse backgrounds from being a school counselor to teachers of different core subject areas. Although the general perceptions of the school principals regarding effective STEM instruction were similarly centered on engagement, problem-solving, and real-world applications, other nuances were found when principals were asked to respond to certain video clips of STEM classes. For instance, Sterrett et al. noted that in response to a video clip of a teacher modeling mathematical concepts with M&M candies, the former principal who had experience teaching middle school mathematics criticized it as "lacking rigor," while the other principals found the activity commendable (p. 185). Another key finding was that the principal who formerly served as a school counselor admitted to having difficulty due to their limited content knowledge, leaving many decisions up to the teachers

(Sterrett et al., 2018). These findings indicate that principals, as major players in the education system, may also require professional development to adapt to the transition to integrated STEM.

Overall, the literature on integrated STEM indicated that the current period is still one of transition for STEM. The lack of a universal standardized definition of STEM makes this transition period difficult, as educators have no clear idea on how to implement STEM education (Carmichael, 2017; English, 2016; Li et al., 2020). Several researchers have found that disciplinary and siloed approaches to STEM are still being practiced in many schools across the world (El-Deghaidy et al., 2017; English, 2016; Widya et al., 2019). In particular, a lack of focus on engineering as a major discipline in STEM was found in several studies (El-Deghaidy et al., 2017; Holmlund et al., 2018; Peters-Burton & Johnson, 2018). As more attention is being given to integrated STEM education, researchers have highlighted the need for professional development for both teachers and principals to increase their preparedness and allow them to transition more smoothly to the integrated approach (Ames et al., 2017; Fraser et al., 2018; Holmlund et al., 2018; Sterrett et al., 2018). Gradual transition and collaborative efforts were cited as potential strategies for transitioning to STEM (El Nagdi et al., 2018; Gardner, 2017; Lesseig et al., 2017). Further research is needed to enable more evidence-based practices and policies for integrated STEM education.

PreK-12 STEM

An important area of research in integrated STEM is the early developmental period encompassing K-12 before the student decides on their career or college majors. Scholars have indicated that interest in STEM must be fostered as early as elementary levels (Hurst et al., 2019; Lesseig et al., 2017). Fostering interest in STEM can influence students' decisions to pursue a STEM-related career as they grow more confident and motivated in this field (Ramli et al., 2020). Affirming students' capabilities early on with challenging STEM skill-building programs will prepare them mentally and emotionally for advanced high school STEM education, and further on, STEM careers (Crabtree et al., 2019). Early exposure to STEM can also help to prevent issues such as math anxiety and negative stereotypes about STEM (Hurst et al., 2019). Alternatively, young children who have had no exposure to STEM principles and skills might come to fear STEM-related fields (Crabtree et al., 2019). As such, it is important to examine the literature surrounding STEM opportunities presented to young children that may be helpful for early childhood STEM education and policymaking.

Despite the increased attention on STEM in the past decades, there remains a lack of research regarding early childhood STEM education (Park et al., 2017). The National Research Council stated in 2011 that the K-3 age level was crucial for developing STEM interest and skills, as children of these ages are natural explorers. Developing their inquiry and critical thinking abilities at this age would serve as an advantageous complement to their natural curiosity (Park et al., 2017). With proper support and well-designed curricula, students may develop higher levels of STEM understanding as early as preschool (Aldemir & Kermani, 2017). Flores et al. (2017) likewise indicated a need to explore a K-20 perspective wherein education systems forge a path of STEM development for children as early as kindergarten up until college completion. This path is unfortunately blocked by a barrier between K-12 and college education, wherein policies and practices diverged, making the transition to higher education difficult (Flores et al., 2017). Although scholars seem to agree that early childhood STEM education is important, progress in bringing STEM to the K-12 setting appears to be slow.

Researchers have examined the barriers to early childhood STEM education. A large portion of these barriers involve teacher preparation (El-Deghaidy et al., 2017). The discussion on professional development in the earlier section revealed that teachers are still generally unprepared to transition into integrated STEM. A study on Chinese kindergarten teachers revealed that although teachers may have positive attitudes regarding early childhood STEM education, they may lack confidence regarding STEM content and methods of teaching (Tao, 2019). An interesting finding from this study was that teachers' years of teaching experience and educational attainment were not related to their confidence in teaching STEM (Tao, 2019). Similarly, Park et al. (2017) investigated the perceptions of teachers in preschool to third grade within the rural areas of Western Kentucky. The majority of these teachers also held positive attitudes about early childhood STEM education; however, a significant number (30%) did not believe that it was appropriate in such an early level. One of the reasons cited by the teachers who did not support early childhood STEM was that literacy was more important at this young age. As a participant elaborated, "if you can't read, you can't do any of the other areas" (Park et al., 2017, p. 284). Teachers also cited other barriers to teaching early childhood STEM, such as the lack of time, resources, professional development, administrative support, parental participation, and knowledge, particularly about engineering (Park et al., 2017). This relatively new approach to education is unfamiliar for all teachers, especially at the early education level, which is farthest from the traditional conceptualization of technology and engineering as tertiary level subjects. The Virginia STEM Education Commission (2020) acknowledged the gaps in STEM professional development, the lack of resources for educators and institutions, and lack of policies for the various STEM-related barriers. Based on these gaps and barriers, the commission has presented potential solutions, such as establishing a STEM hub for better access to resources and various professional development programs (Virginia STEM Education Commission, 2020). Following up on these plans would be crucial for the transition period towards better integrated

STEM. As such, more evidence is needed as to how STEM could be properly implemented in early childhood education and how to prepare teachers for it.

STEM Schools

While the ideal scenario would be to have integrated STEM education available in all schools and accessible to everyone, this scenario may still be a long way away. As aforementioned, the 2010s to 2020 still represent a period of transition for integrated STEM education. Nonetheless, some STEM-focused schools have existed in certain states since the 20th century, mostly for gifted children (Carmichael, 2017; Means et al., 2017). These pioneer STEM schools were mostly exclusive, with highly competitive admission requirements. These schools mainly targeted the population of students who excelled in science and mathematics (Means et al., 2017). Offering exclusive education with elements such as integrated projects, collaborative approaches, high-end facilities, and most importantly, their intellectual property of an advanced curriculum made these exclusive STEM schools highly selective and sought after (Bullock, 2017). STEM schools have become more popular since then, especially when former President Barack Obama introduced the goal of having 1,000 new STEM schools in the United States by 2020 (Bullock, 2017). While these STEM schools served as milestones for the development of STEM education, most of them remained strictly selective and inaccessible to most students.

The development of magnet schools presented an important initial step to inclusive STEM education. Magnet schools are public schools that provide tailored educational programs to various types of students (Riel et al., 2018). As part of the public-school system, magnet schools must abide by the state's educational laws, including the prescribed curriculum (Riel et al., 2018). The origin of magnet schools rested on the period of racial desegregation (Means et al., 2017; Riel et al., 2018). The Supreme Court decision following the *Brown v. Board of*

Education case, in particular, brought on the need to have a public school that can attract a diverse set of students. As such, magnet schools were advertised as schools for the gifted, offering special programs and facilities so as to keep white parents interested in these diverse schools (Means et al., 2017). While magnet schools present opportunities for students in marginalized groups, admission in these schools may still be selective (Means et al., 2017). As such, only students who already show an aptitude for STEM disciplines may be admitted (Lynch et al., 2018). Students who do not satisfy the requirements, regardless of race, are still deprived of a proper STEM education.

A less selective option emerged for STEM education in the form of inclusive STEM high schools (ISHSs). These ISHSs aimed to provide greater equity by providing access to STEM education to historically underrepresented students in education (Lynch et al., 2018). Unlike magnet schools, admission for ISHSs are mostly based on interest in STEM. If the number of applicants exceeded the maximum, a lottery system would be utilized to avoid any type of bias (Lynch et al., 2018). The absence of strict admission requirements meant that students from varying levels of ability may enroll in ISHSs (Peters-Burton & Johnson, 2018). The main goals of ISHSs are to ensure that all students in the United States are provided an opportunity to increase their science literacy, prevent the phenomenon of the leaky pipeline (see Figure 1), and prepare these students for STEM higher education and careers (Means et al., 2017; Peters-Burton & Johnson, 2018). Based on these goals and admission systems, ISHSs appear to be the ideal setup to promote STEM education for all types of students.

As newer types of schools, ISHSs may not be as well-established in both research and practice. Vaval et al. (2019) indicated a lack of consensus in the literature regarding the criteria for considering which schools fall under the category of ISHSs. Means et al. (2017) indicated that most ISHSs followed a school-within-a-school format that provided intensive programs of STEM within schools. They further distinguished these schools from those wherein STEM programs were only open to select students. Common features of ISHSs include methodical preparation for STEM-focused higher education, project- or problem-based approaches, provision of supports for students who may need it, incorporation of life- or job-related skills, supportive school climate, and external partnerships for STEM learning outside of school (Means et al., 2017). Johnson and Sondergeld (2020) examined a single ISHS in Tennessee. This specific ISHS followed the I-STEM framework, which emphasized integration through practices of scientific inquiry, technological and engineering design, mathematical analysis, and other competencies necessary for the 21st-century student. The authors compared data from the intervention group, which was the ISHS, to 13 feeder high schools in the same district as a control group. Their findings revealed that ISHS students had higher course mastery, higher college readiness, and higher attendance rates. These findings highlighted not only the increased competencies developed by I-STEM, but also the increased interest of students in the form of attendance, thus highlighting the benefits of integrated STEM and inclusive opportunities for all students (Johnson & Sondergeld, 2020).

On the contrary, some researchers have brought forward possible barriers and disadvantages of ISHSs. Bullock (2017) noted that the nonselective nature of ISHSs often resulted in a chaotic curriculum as educators attempted to meet various students' needs. This is in contrast to selective or exclusive STEM schools wherein educators could deeply engage in STEM concepts and principles within their curricula, as the selective nature of their admission ensured that students had at least a basic understanding of STEM. Furthermore, selective schools could allocate more resources to advanced courses and projects rather than remediation courses, which is likely the focus of ISHSs' budgets (Bullock, 2017). Jorgenson (2018) also indicated that ISHSs were still subject to state requirements, which meant that there is an increased pressure in ensuring that students met state standards.

A more generalized issue of STEM education as a whole is that it may not necessarily lead to STEM-related careers (Bottia et al., 2017). Bottia et al. (2017) conducted a longitudinal study to determine the relationship between secondary STEM education and STEM-related college outcomes. Students from STEM high schools were matched with students from other schools that did not offer STEM-oriented programs. The results revealed no significant relationships between attending a STEM-oriented high school and the three dependent variables. Bottia et al. concluded that the increased STEM courses, increased information about STEM careers, and presence of peers interested in STEM provided within STEM-oriented high schools may not be enough to influence students' STEM-related college outcomes and subsequent careers. Instead, they purported that family or individual factors may be more influential (Bottia et al., 2017). Although these findings may be discouraging, it is possible that more improved STEM integration and STEM schools may produce better outcomes. As educators' perceptions of integrated STEM continue to develop through this transition period, further investigation of STEM schools is needed to keep up with developments.

Although associated more towards CTE than STEM, career academies are also places of learning for STEM fields (Kinoshita, 2020). Career academies were originally established as intervention-based programs for at-risk students to improve their employability. The design of career academies is based on three dimensions: small learning communities, external partnerships with corporate and other academic institutions, and a preparatory curriculum based on a career theme. Inclusive education is also emphasized in career academies, making them more accessible to minorities to pursue STEM fields than STEM-oriented schools (Kinoshita, 2020). Work-based learning programs across states have also been established to prepare students for postsecondary education or the workforce as early as elementary levels (Zinth, 2018). The Virginia Department of Education (n.d.) has outlined requirements for work-based learning, including a focus on career awareness, career exploration, and career preparation. The methods for work-based learning included job shadowing, service learning, mentorship, externship, internship, school-based enterprise, clinical experience, entrepreneurship, cooperative education, and registered apprenticeship. Institutions must also prepare training agreements and training plans for work-based learning. Institutions in Virginia have been working on these requirements; however, there was a waiver for them due to the COVID-19 pandemic. Nonetheless, institutions, along with the Virginia Department of Education (n.d.), continue to work to provide practical work-based learning for students. Work-based learning also focuses on employability and skill-building. These programs align learning opportunities with state job demands and provide support for students with efforts, such as career counseling (Zinth, 2018). These programs and academies present additional options that may help prepare students for STEM careers.

STEM Curricula

An area of STEM education that deserves more attention is the STEM curricula. The lack of a standardized definition of integrated STEM can make curriculum design difficult. Nonetheless, certain aspects of a STEM curriculum have been examined in the literature. The first aspect is the problem-based approach to teaching, which involves real-world problems with no obvious solutions (Lesseig et al., 2017). The incorporation of the engineering design, discussed previously in earlier sections, represents a problem-based approach with its focus on applying content knowledge to a certain problem (Margot & Kettler, 2019). The problem-based approach often requires the integration of learned concepts and principles from the four STEM disciplines to arrive at possible solutions. This thinking process is important for preparing students for the real-world settings where problems are also complex and not siloed into individual disciplines (Rennie et al., 2017). This approach was also purported to encourage mastery learning or learning through failure, which was also reflective of real-world problems and encouraged students to attempt alternative solutions upon failure (Lesseig et al., 2017; Peters-Burton et al., 2018). The integrated STEM curriculum is thus considered to be more helpful in preparing students in terms of both life and job-related skills.

A specific STEM curriculum called Project Lead the Way (PLTW) has been a prominent topic in the literature. PLTW is a national program that prescribes a STEM curriculum with an emphasis on collaboration between public schools, institutions of higher education, and industries in the field of engineering (Godfrey, 2018). Students under the PLTW curriculum were reported to obtain higher scores on standardized exams (Pike & Robbins, 2019). Participants from Godfrey's (2018) study, who were taught under the PLTW curriculum, scored higher in cognitive reflection. A research project by the One8 Foundation in Massachusetts evaluated the PLTW curriculum based on preliminary findings of a 6-year project (Papay, 2019). With the aid of One8 school grants, the number of students in PLTW courses have increased, particularly for Hispanic and Black students, in Massachusetts. Findings revealed how PLTW coursework was related to increased student scores for all students, including economically disadvantaged students and students with disabilities. Reports from students and teachers further indicated significant satisfaction with the PLTW. Feedback from teachers and professionals was noted as a valuable component by students, while online training was a valuable component for teachers (Papay, 2019).

In contrast, Utley et al. (2019) noted that participation in PLTW was not significantly different than their non-PLTW peers with retention in engineering degree completion. However, Utley et al. did find that students who participated in PLTW did tend to persist at a higher proportion than expected when looking at year one and year two enrollment in engineering programs. Additionally, minority students also withdrew from their first to second year at a significantly lower rate than expected if they had participated in PLTW. This study was limited to only two groups of students at one college. It would be worth expanding to more colleges across multiple states to determine whether the findings are consistent. Utley et al. also stated there is little research that compares multiple curricula and if they are, in fact, effective with helping reduce the leaky pipeline in college engineering programs. PLTW curriculum is just one of several possible models of STEM curriculum. Further evidence for other STEM curricula may help to inform policies for STEM education.

Extracurricular Opportunities

Aside from the STEM curriculum, another important element of STEM education is the availability of extracurricular opportunities for learning. Activities such as joining clubs or summer camps allow students to explore STEM in creative and interesting ways without the added pressure of grades (Dasgupta & Stout, 2014). Some STEM schools also have centers where students can access services such as tutoring, academic and career advising, social meetings, and other helpful resources (Eastman et al., 2017). These after-school activities and programs may promote continuous learning even outside of the classroom.

A specific extracurricular program called Makerspaces was recommended by Woods and Hsu (2019). Makerspaces are spaces for learning through creation, following the principles of constructionism. Three elements define Makerspaces: the makers, the makerspace, and the making. Makerspace activities comprise playful manipulation and exploration, making it useful for STEM learning. Woods and Hsu recommended the implementation of makerspaces in informal STEM learning settings, such as libraries. Library makerspaces could include materials varying from craft supplies and LEGO bricks to more advanced 3D printers and robots to meet the needs of children of different ages and levels. Librarians are expected to teach problem-solving through design, implementation, and reflection as well as provide opportunities for making and model persistence to students. Their main roles in library makerspaces would be as co-learners to students as they learn from hands-on activities. Based on this design, the library makerspace may be a useful program for school libraries to increase knowledge, skills, and interest in STEM (Woods & Hsu, 2019). As STEM education continues to develop and the STEM curriculum becomes more refined, researchers and practitioners could also explore other extracurricular STEM opportunities that could further enhance STEM education.

Researchers could also establish external partnerships with informal learning settings to expand students' STEM learning. These informal settings can include museums, science centers, or even the students' homes (El-Deghaidy et al., 2017; Hurst et al., 2019). Partnering with students' parents to extend their learning at home through play may be an inexpensive strategy for STEM education. An emphasis on social, playful, and engaging activities make these informal learning centers interesting for children. Within these settings, children can freely choose the activities inspired by their own curiosity and have more control over their learning (Hurst et al., 2019). Museums were particularly cited in much of the literature on informal STEM learning, as these settings provided real-world applications associated with STEM concepts (Dasgupta & Stout, 2014; Hurst et al., 2019). Hurst et al. (2019), however, noted the need for increased accessibility and cultural relevance in museums for minority students. Pop-up or traveling museums are examples of how to provide easier access to this informal setting in locations that otherwise had limited exposure to museums (Hurst et al., 2019). Informal settings of STEM learning could be an effective way to increase interest in STEM, especially for underserved populations and locations.

The knowledge obtained in museums was purported to be ineffectual without knowledge transfer or the ability to retain and apply the learned knowledge to other contexts (Marcus et al., 2017; Tougu et al., 2017). Even though museums and other informal settings provide hands-on interactive learning activities for children, these children may not be able to transfer the knowledge they gained to other contexts in their lives (Marcus et al., 2017). Marcus et al. (2017) suggested that strategies such as initiating parent-child conversations about the learning activity may promote knowledge transfer. They investigated this hypothesis with 40 mother-child dyads, with the children aged 5 to 6 years, in the Chicago Children's Museum. Their intervention involved in-depth engineering information sharing. All mother-child dyads then participated in a series of activities, with the intervention group receiving more engineering information along the way. As expected, the intervention group performed better in the activities than the control group, exhibiting better knowledge transfer (Marcus et al., 2017). Tougu et al. (2017) similarly examined knowledge transfer by investigating the effect of a demonstration of engineering principles to families before participating in an activity with their children. Their study, also within the Chicago Children's Museum, involved 277 children with an age range of 6 to 10 years. Children of the families who experienced the demonstration intervention built sturdier structures in the activities, suggesting increased knowledge transfer, as compared to those who did not experience the intervention (Tougu et al., 2017). These findings suggested that explicit instruction within these informal learning settings may enhance STEM learning.

Partnerships

Aside from informal learning settings, schools can also partner with higher education institutions and workforce industries. These partnerships could help not only students but also teachers to better understand how interdisciplinary lessons and projects could be designed (El-Deghaidy et al., 2017; Jang, 2016). Partnering with higher education institutions also opens up opportunities for college grants and mentoring opportunities for students (Carmichael, 2017; Dasgupta & Stout, 2014). Interacting with real STEM professionals may help to inspire children to enter the STEM field (Dasgupta & Stout, 2014). A specific program called career academies emphasized these partnerships and based their curricula on college and career preparation (Kinoshita, 2020). Professionals from partner institutions worked hand-in-hand with school leaders of these career academies to ensure that their curricula were aligned with college and career goals (Kinoshita, 2020). These partnerships present valuable opportunities for students and educators, making them vital considerations for STEM policies.

In the state of Virginia, it was recommended that regional STEM hubs be established to produce a local initiative for STEM through coordination and shared community efforts to deconstruct STEM misconceptions and to identify STEM champions within the community (Virginia STEM Education Commission, 2020). These hubs could represent small STEM partnership networks wherein STEM language, communication, programming, and best practices are developed and disseminated throughout. Hubs also provide public STEM opportunities for communities such as through out-of-school-time programs, community programs, or newsletters

(Virginia STEM Education Commission, 2020). Through partnerships developed in STEM hubs, students, teachers, and institutions can easily share information with each other.

The literature on K-12 STEM presented in this section revealed the importance of establishing STEM interest and abilities in early childhood education (Hurst et al., 2019; Lesseig et al., 2017). Some barriers and disadvantages to early childhood STEM education were noted, such as teachers' unpreparedness and the greater need to focus on literacy (Park et al., 2017; Tao, 2019). With these inconclusive findings, STEM education in early childhood remains an underexplored topic. Researchers have also presented the advantages and disadvantages of various types of STEM schools, including exclusive STEM schools, magnet schools, and ISHSs (Bullock, 2017; Johnson & Sondergeld, 2020; Lynch et al., 2018; Means et al., 2017; Riel et al., 2018; Vaval et al., 2019). Elements of the STEM curricula and extracurricular STEM opportunities were also presented (Eastman et al., 2017; Godfrey, 2018; Lesseig et al., 2017; Peters-Burton et al., 2018; Woods & Hsu, 2019). Informal learning settings and partnerships with other institutions were cited as valuable resources for STEM learning and motivation (Dasgupta & Stout, 2014; El-Deghaidy et al., 2017; Hurst et al., 2019; Kinoshita, 2020). Findings from this group of literature generally pointed to the various opportunities of developing STEM abilities and interest early on for young children, which may be useful in STEM policymaking for K-12 settings.

Opportunity and Access to STEM

While opportunities for STEM education continue to evolve, the selectivity behind these opportunities may be perpetuated by some policies. A common misconception is that STEM education is a choice (Bullock, 2017). Specialized STEM schools and programs create the notion that STEM is an option that one can take, and that those who do not take this option do so freely.

This perception, however, ignores the issue of accessibility. Bullock (2017) indicated that minorities of low socioeconomic status would seek quality STEM education for their children if possible, but they continue to be disempowered by policies and structures of selectivity in STEM education. As such, the white male population continues to be the dominant population in STEM education (Utley et al., 2019). Issues of diversity and inclusion in STEM are, therefore, vital, as the potential of these underserved children may be wasted if the nation does not invest in their talents (Crabtree et al., 2019). Underserved populations such as racial minorities, females, and students with disabilities deserve increased attention in the field of STEM.

Underrepresentation in STEM fields

Several researchers have noted an underrepresentation of women and racial minorities in STEM fields, both in education and in the workforce (Briggs, 2017; Bullock, 2017; Goris, 2020; Hill et al., 2018; Xu, 2015; Young et al., 2017). Even when women somehow managed to obtain STEM-related careers, the pay gap between genders in these fields are still troubling (Xu, 2015). This inequity shows that issues of STEM education and policy go beyond the simple provision of STEM curricula in schools.

Inequity and underrepresentation are among the most cited issues within STEM research. The term “leaky pipeline” has been cited as a metaphor for high attrition rates of minorities within STEM education and careers (Dasgupta & Stout, 2014, p. 21). As a growing population in the United States, racial minorities represent an untapped potential that may contribute to the STEM fields (Briggs, 2017). As the STEM workforce becomes older, the need to harness this potential becomes greater. Providing more opportunities for racial minorities to pursue STEM education and careers may benefit the country’s economy and security; however, these individuals continue to experience barriers brought on by litigation and budget restraints (Briggs, 2017). STEM-focused schools could be constructed, and more STEM-related job openings could be provided; however, without specific strategies and intentional outreach, students who struggle with access to economic resources may still be excluded. Issues such as poverty, Internet access, and lack of resources not only prevent struggling communities from entering STEM-focused schools but also from sustaining an optimal level of well-being to succeed (Bullock, 2017). Bullock (2017) highlighted the continued suffering experienced by African American students in the schooling system, as traces of the antebellum era and segregation remain. Although school integration was prescribed as an answer to segregation, the prejudicial foundations of education remain and persist in preventing African American students from obtaining high quality education (Bullock, 2017). The roots of racial inequity in STEM education appear to run deep, requiring major efforts to fully support African American and other racial minority students and promote racial diversity in STEM. One practice that perpetuates these inequities is tied to entrance criteria of some STEM schools and the red tape and family involvement needed to navigate bureaucracy and apply to specialized schools (Flores et al., 2017). Students' high school experiences, which may be influenced by STEM barriers, are crucial to their learning experiences and future (Flores et al., 2017).

The issues of diversity and equity are not limited to race. Several researchers noted that women continue to be underrepresented in the STEM fields (Cheryan et al., 2017; Dasgupta & Stout, 2014; Master et al., 2017; Stoet & Geary, 2018). Ironically, Stoet and Geary found an educational gender equality paradox wherein large gender gaps in STEM were found in countries with high levels of gender equality, such as Finland, Norway, and Sweden. In these countries, female students generally performed better than male students in science literacy; however, a large majority of STEM-related degree holders in these countries were male (Stoet & Geary, 2018). Cheryan et al. (2017) purported that the gender gap in higher education STEM was an issue of recruitment rather than retention, as it appeared to be more difficult to get equal numbers of male and female enrollees in STEM than it was to maintain the numbers of female and male students in STEM. The leaky pipeline for gender appears to begin earlier than the tertiary level, thus calling for policies that promote gender equity in STEM as early as primary and secondary levels of schooling.

Perhaps a less noticeable gap in the STEM fields is the gap involving students with disabilities (SWDs). Although gender and race are important factors, inclusive education would not be truly inclusive if it excluded the group of SWDs. In the United States, SWDs are largely underrepresented in STEM education (DeWitt, 2020). While SWDs earn equal numbers of credits in English as their peers, they receive significantly lower numbers of credits in STEM (DeWitt, 2020). Although SWDs are included in the National Science Foundation's (NSF) report on STEM underrepresentation, evidence regarding their performance and experiences in STEM education and STEM careers are extremely limited, perhaps due to state differences in definitions of disability (Thurston et al., 2017). Furthermore, research that does include SWDs often grouped these disabilities together without distinguishing students with and without intellectual or learning disabilities (DeWitt, 2020). The invisibility of the SWD population in STEM research could represent an important gap that influences STEM policies.

The issues surrounding minority underrepresentation in STEM are further complicated by the intersection of minority statuses. Studies surrounding SWDs in STEM often disregard the influence of gender, even though findings have pointed to the marginalization of female SWDs (Kolne & Lindsay, 2020). African American female students are also significantly marginalized in STEM fields (Young et al., 2017). The theory of intersectionality explains how individuals with intersecting minority statuses may experience unique challenges and barriers than individuals with a single minority status (Ireland et al., 2018). As researchers focused on experiences of racial minorities and women separately, the unique experiences of female racial minorities remain unaccounted for (Ireland et al., 2018). These gaps, both in terms of STEM participation and research focus, highlight unresolved issues that should be considered in STEM policymaking.

Racial Minority Gap

Despite the supposed desegregation in U.S. education, racial minorities still suffer from discrimination. Statistics regarding college completion from the years 1990 to 2014 revealed that the racial gap in U.S. education has widened from 13% to 18% for the White-Black gap and 18% to 26% for the White-Latinx gap (Flores et al., 2017). Flores et al. (2017) conducted a study on Texas graduates based on longitudinal administrative data and revealed that many of the problems with the racial gap in education could be due to precollege characteristics that disempower racial minorities. Their findings revealed that the achievement gap between White and Latinx students may close by 17.1% if Latinx students were given the same opportunities as White students, and the gap between Black and White students may close by 30.5% under the same conditions. Being in a high-minority secondary setting was a significant factor that influenced these gaps. Poverty was also a factor for Latinx students, while academic preparation was a significant factor for Black students (Flores et al., 2017). It appears that racial minority students are highly disadvantaged early on in education because of these factors that are not related to their abilities.

Potential solutions have been offered for the racial achievement gap. For instance, Bosch et al. (2019) investigated the effects of seven semesters of online STEM education university students and found that the online setting was beneficial for underserved racial minority students, as it reduced the stereotypical pressures that impeded on their learning in face-to-face classrooms. Another recommended way to ease the negative stereotypes about underserved racial minority students, particularly in ISHSs, was to offer tutoring in the form of support rather than as remedial services (Lynch et al., 2018). Offering support for students who may initially struggle with STEM in these inclusive schools may be more helpful in boosting self-efficacy and confidence with STEM, rather than offering remedial classes that may lead students to think that they lacked the ability to pursue STEM education or careers (Lynch et al., 2018). Cessna et al. (2018) also provided several recommendations for first generation racial minority students, who may experience culture shocks or cultural incongruence upon entering higher education, particularly for STEM degrees. The authors recommended having a “cultural broker” or a facilitator that helped students adapt to the unfamiliar setting of higher education and STEM and allowed for smoother cultural transitioning (p. 10). They also emphasized the importance of developing self-efficacy and a STEM identity early on in students before entering higher education (Cessna et al., 2018). Establishing a science identity for racial minority students through an emphasis of positive role models, such as displaying materials regarding Black scientists of the past, may also be helpful, especially considering the limited representation they still have in STEM fields (Brown et al., 2017). These are just some of the possible ways to reduce the racial achievement gaps in STEM education. More research is needed to provide more strategies or further evidence for these recommendations.

Gender Gap

Another prominent issue in STEM education is the gender gap. Women continue to be underrepresented in STEM fields and careers (Cheryan et al., 2017, Goris, 2020). The gender gap in STEM education has been identified as an issue of discrimination rather than actual abilities. Although female students in the United States achieve higher grades in science than male students, they are less likely to pursue science as a college major or as a career (Hill et al., 2018). Dasgupta and Stout (2014) purported that much of this discrimination and lack of interest in STEM careers are engrained in young girls early on. Their literature review across stages of human development revealed that factors from each stage could influence girls' decisions to pursue STEM careers. Early childhood and adolescent experiences with stereotypes about STEM being a masculine field, parents' influence and expectations, and peer pressure may begin signaling to young girls that they should not pursue STEM. Young adults who attempt to enter STEM-related fields then experience the gender gap in the lower numbers of female peers, mentors, and role models. Upon entering the STEM workforce, women may encounter gender biases in terms of hiring, promotion, work climate, and work-life conflicts (Dasgupta & Stout, 2014). Women continue to suffer from a pay gap in STEM disciplines, even though they had comparative grades with their male peers (Xu, 2015). Specifically, data from 2003 showed that male STEM or medical professionals earned an overwhelming 113% more than their female counterparts. Further aggravating this pay gap is the work-life issue of males being rewarded for being a family man while women were often penalized at work for being mothers (Xu, 2015). The discouraging barriers for females in STEM from early childhood to adulthood show the deep-rooted issues that may perpetuate the gender gap in STEM.

Researchers have explored the nuances in the STEM gender gap. Researchers agreed that the gender gap is greater in the disciplines of technology and engineering, more so than in the natural sciences and mathematics (Cheryan et al., 2017; Master et al., 2017). Cheryan et al. (2017) conducted a literature review of STEM papers since 1990 and arrived at their model showing how masculine culture, insufficient early experience, and self-efficacy were factors influencing the underrepresentation of women in computer science and engineering fields. Specific sub-factors such as stereotypes, work-family issues, lack of role models, ability and performance, labor market forces, and peer support were noted to contribute to the female underrepresentation. They emphasized how the stereotypes of being male, socially awkward, and technology savvy were more prominent in fields of computer science, engineering, and physics than in the natural sciences (Cheryan et al., 2017). Master et al. (2017) agreed and noted that children at a young age were already being led to believe that boys were more adept at robotics and programming through media and gender-labeling, such as in the case of toys. They highlighted data from 2012 showing how women held 59% of biological sciences degrees, 43% of math and statistics degrees, and 41% of physical sciences degrees, showing a trend towards closing the gender gap; however, women only held 18% of computer science degrees and 19% of engineering degrees. Master et al. then emphasized the importance of eliminating stereotypes and building girls' interest in STEM early on. In their study, they allowed young girls to play with an intentionally designed programming game and compared them with control groups that underwent either no activity or a storytelling group. Findings revealed how the girls in the programming group displayed significantly higher technology motivation than the other two groups, emphasizing the malleability of girls' interest in STEM (Master et al., 2017). Based on these findings, there appears to be a greater need for motivating young girls' interests in the fields of technology and engineering.

Adding to the problematic gender gap in STEM are issues of intersectionality. Young et al. (2017) emphasized that the intersection between the female gender and being a racial minority presented unique experiences for dually marginalized students in STEM, particularly for young black girls. Black female students are largely underrepresented in STEM fields, with only 10.4% of female STEM graduates being black. As such, Young et al. sought to investigate the relationship between participation in advanced secondary science courses and science dispositions for Black female high school students and found that the relationship between these variables was significant and strong. Science identity, or the belief that one is a “science person,” should thus be developed in young black girls early on to increase their interest and motivation in pursuing STEM education and careers (Young et al., 2017, p. 176). The unique experiences that intersectionality may bring to students is another factor that should be considered by STEM policymakers.

Students with Disabilities

A relatively less discussed population in STEM education is the population of students with disabilities (SWDs). Students with disabilities comprise a wide range of individuals with varying levels of abilities (DeWitt, 2020). What may not be obvious for some is that many SWDs are actually capable of pursuing STEM careers (Schreffler et al., 2019). These students, however, may not receive the proper support to meet their potentials. The lack of support and attention given to SWDs in the field of STEM may be demotivating, causing these students to abandon their interest in STEM (Schreffler et al., 2019). The population of SWDs represents another waste of talents and skills that may contribute to STEM.

Students with disabilities (SWDs) have unique needs that require additional support from educators. Unfortunately, most educators are unprepared to meet these needs or even to recognize them (DeWitt, 2020). Preparedness for teaching SWDs adds to the already numerous barriers that teachers may face in the transition to integrated inclusive STEM education (DeWitt, 2020). Schreffler et al. (2019) recommended the strategy of universal design for learning (UDL) to help educators design their classrooms and lessons. The UDL takes its roots from architecture as a way to design products or environments that may be used by everyone without needing additional adaptations. Schreffler et al. gave the example of the curb cut, which allowed access to individuals with mobility disabilities. The curb cut not only met the needs of individuals with disabilities, but also helped other individuals, such as those with strollers or bicycles. This principle of UDL could be utilized in STEM classes to make them more accessible to everyone, regardless of disability status. For instance, strategies such as increased visual aids and electronic learning supports in classrooms provides more access to learning for SWDs (Schreffler et al., 2019). As an underexplored population in STEM research, SWDs should be given more consideration in STEM education and policies.

Overall, the literature in this section revealed the gaps in STEM education for racial minorities, gender, and SWDs. Black and Latinx students continue to be underrepresented in STEM (Flores et al., 2017). Women were also underrepresented in STEM, and the research revealed the depth of the gender gap as stereotypes are developed early on in childhood, especially in the fields of technology and engineering (Cheryan et al., 2017; Master et al., 2017; Xu, 2015). The intersection between race and gender further aggravates the STEM achievement gap (Young et al., 2017). Students with disabilities are also underrepresented in STEM education as well as in STEM research (DeWitt, 2020; Schreffler et al., 2019). Although some strategies have been recommended in the literature to help close these gaps, more evidence is needed to inform policies that may help these students succeed in STEM.

Structures Within the Educational System

A final related area of research that is crucial to STEM education and policy involves the structure of the local school division. Urban and rural locations appear to have their own advantages and disadvantages in terms of STEM education (Hill et al., 2018). While rural areas are lacking in STEM-related infrastructures such as museums and zoos, these areas may have natural resources within their communities, such as farms, that could also serve as learning sites for STEM learning. Urban areas, while seemingly ideal for STEM learning due to the available infrastructures, may be fraught with other obstacles, such as economically segregated areas and social isolation. Researchers may overlook these advantages and disadvantages when reporting STEM-related findings in urban and rural settings (Hill et al., 2018). Many areas around the United States may also be undergoing gentrification or urban repurposing, which may affect schools within that area (Bullock, 2017). In some states, schools that fail to meet state standards are repurposed into selective STEM schools that served to retain only middle-class families, while lower-class families are forced to find new schools (Bullock, 2017). These local structure factors highlight the importance of considering urban and rural areas as well as small and large school divisions in STEM education and STEM policy research.

Local Policies

An important aspect of STEM education, especially in the United States, is the local policy. States may differ in terms of school standards and opportunities provided for potential STEM students (Carmichael, 2017). The establishment of ISHSs in states such as Texas, Ohio, North Carolina, Arkansas, Tennessee, Arizona, and Washington are just some examples of how state policy can influence STEM education (Lynch et al., 2018; Means et al., 2017). State funding also influences STEM-related outcomes, as those with STEM metric incentives produced more STEM graduates than those who did not adhere to such funding policies (Li, 2020). An overview of these state policies would be helpful in establishing a picture of the STEM status in the United States.

Urban Areas

Before proceeding with specific discussions on state policies, it is important to understand the nuances in locale categories such as urban, suburban, and rural. As aforementioned, each setting may have their own advantages and disadvantages in terms of STEM learning (Hill et al., 2018). Generally, urban areas are portrayed to have greater diversity than suburban and rural areas, while rural areas are presented as predominantly white (Seals et al., 2017). As such, researchers and policymakers look to urban schools for diversifying the STEM workforce (Young et al., 2017). Unfortunately, urban schools suffer from certain difficulties such as chronic absenteeism and inequities (Johnson & Sondergeld, 2020). Additionally, urban schools suffer from higher rates of teacher attrition, which may reduce the quality of education in such areas (Borman & Dowling, 2008). Educational efforts in urban areas also appear to be centered around severely underperforming students, leaving high-achieving students unmotivated (Eastman et al., 2017). The large number of STEM learning settings in urban areas may also be offset by their inaccessibility for students in lower socioeconomic statuses (Hill et al., 2018). Research surrounding STEM education in urban settings thus appear to focus on providing more equitable access to STEM learning for a diverse population of students.

The size of school districts and population within urban areas also presented as STEM issues in the literature. Large urban districts encompassed highly populated institutions wherein teachers struggled with overcrowded classes, smaller teacher-student ratios, lack of parental support, and other material scarcities, such as poor classroom acoustics and lack of classroom dividers (Jorgenson, 2018; Seals et al., 2017). Larger school districts also meant less specialized and less individualized professional development for educators (Seals et al., 2017). Seals et al.

(2017) noted that professional development in these large districts often meant brief and vague workshops. For students, large school districts can be particularly difficult to navigate for both SWDs and first-generation students (Cessna et al., 2018; Schreffler et al., 2019). These difficulties faced by large urban school districts should be taken into consideration for STEM policymaking.

Rural Areas

On the other hand, rural areas mostly encompass smaller school districts with limited infrastructures (Tyler-Wood et al., 2018). These small school districts generally received less funding for education due to the lower number of enrollees (Tyler-Wood et al., 2018). Some disadvantages associated with rural schools include less professional development opportunities for educators, lower bandwidth for Internet-based learning, and less infrastructures for informal learning (Hill et al., 2018; Thomas & Falls, 2019). Hill et al. (2018) found that, while students in rural areas expressed more interest in joining after-school clubs and programs, there were few resources to support such programs, unlike in urban settings. Hartman et al. (2017) presented the "Museum for All" initiative, which aimed to provide greater access to children's STEM museums in rural areas; however, this program is still relatively new and lacks empirical evidence. In addition to these disadvantages, Tyler-Wood et al. (2018) noted that rural areas were more widespread than urban areas, making transportation more difficult for students. As much of the funding goes to transportation, minimal funding is left for other resources such as computers (Tyler-Wood et al., 2018). The lack of funding is particularly damaging to STEM education, as rural areas are cut off from technological equipment, including the capacity to maintain and upgrade them (Jarvis, 2018). Based on these barriers, it may be more beneficial for

STEM policies in rural areas to focus more on providing access to more learning opportunities and technologies to students.

State Initiatives

Aside from differences in locale settings, researchers have also focused on state-specific STEM initiatives. The state of Texas was especially notable, with its program T-STEM having the largest investment for ISHSs in the United States (Saw, 2018). The ISHSs within the T-STEM program focused on rigorous college preparation for all students, problem-based approaches, network supports for students, career and life-related skill building, supportive school climate, and external partnerships with other institutions (Means et al., 2018). Saw (2018) examined the effects of these ISHSs in Texas and found that while the relationship between ISHS attendance and achievement in science and mathematics was insignificant, ISHS attendance was related to more mathematics credits and courses. An important finding from their study was that ISHSs positively affected the high school graduation of underserved racial minorities and students of low socioeconomic status (Saw, 2018). Means et al. (2018), who also studied the T-STEM, found the T-STEM to be an effective program for promoting STEM higher education, especially for Latinx students, female students, and students of low socioeconomic status. Based on these findings, it appears that Texas's T-STEM initiative has been successful in promoting equity in STEM education.

Other states also had their own STEM initiatives. In North Carolina, the NC New Schools Project by the Bill and Melinda Gates Foundation was found to promote better STEM learning and higher GPAs, especially for female and African American students (Means et al., 2017). Policymakers in California were reported to be exploring a new admission system that would increase guaranteed student admission rates from 4% to 9% across the state; however, details regarding this initiative is extremely limited (Briggs, 2017). The Ohio Department of Education also enacted efforts to improve partnerships between STEM schools, higher education institutions, and businesses (Woods & Hsu, 2019). The majority of the STEM schools in Ohio, however, were noted to be in large urban areas, which limited the geographical impact of the initiative (Woods & Hsu, 2019). STEM initiatives in various states were purported to be skewed, with 38 states focusing their funds on science and mathematics, only three states requiring end-of-course technology and engineering exams, only two having professional development efforts for technology and engineering, and none reporting technology or engineering as a critical shortage in STEM education (Wells, 2019). These data showed that, as much as state policies for STEM education have developed, these may not fully reflect the integration of STEM.

The present study focused on the state of Virginia. The estimated growth in STEM-related occupations in Virginia by the year 2024 is 18%, which is double the estimated growth for non-STEM occupations (Mickle, 2020). Industries in demand within Virginia mostly revolve around technology and engineering such as manufacturing, aviation, and computers (Mickle, 2020). In the Tidewater region, there is an increased demand in occupations of shipbuilding and repair as well as military, involving the fields of engineering, programming, and electronics (Virginia STEM Education Commission, 2020). Northern Virginia has a greater focus on computer science and cybersecurity, particularly in terms of military security and intelligence and big data specialists. In Southwestern Virginia, industries of agriculture, construction, manufacturing, and energy are increasing in demand, requiring STEM-related skills such as computer science and robotics (Virginia STEM Education Commission, 2020). These specialized demands of regions in Virginia present the myriad of opportunities for STEM employment.

Efforts to increase STEM education in Virginia have thus increased since the introduction of the STEM education degree at the Virginia Tech University in 2005 (Martín-Páez et al., 2019). One of the major initiatives for STEM in Virginia was the Virginia Governor's STEM Academies, which was launched to improve K-12 STEM education systems across the state (Kinoshita, 2020). Under this program, STEM academies were established, comprising one public school division, some local industries, and a higher education institution. There are currently 21 STEM academies in Virginia. These academies included notably more Asian and Latinx students than White and Black students. There were also more students of low socioeconomic status in these academies. Kinoshita (2020), who investigated these academies, found that early interest and success in STEM was significantly related to participation in the Virginia STEM schools. Additionally, they found that students from the STEM academies performed slightly better in the math and verbal portions of the SAT; however, there was no significant difference in attendance between STEM academies and the control groups. These findings reflect the status of a large part of Virginia's STEM education.

Additional issues with STEM education in Virginia are equity and resource allocation. Neal (2019) noted that self-segregation was prominent in Virginia as families chose to send their children to farther urban areas for STEM education rather than nearby school divisions with the perception of promoting better STEM learning in these large urban areas. Self-segregation based on real estate market was noted to be a perpetuator of the inequities of STEM education (Neal, 2019). Jarvis (2018) indicated a necessity for more enhanced professional development on technology, especially for the rural public-school divisions in Virginia. Corning et al. (2017) focused on the lack of access to higher education institutions within Virginia, as most institutions appeared to serve only middle-class students who can afford to spend on an additional 2 to 4 years of education. They then examined the Virginian school divisions according to the need for resources, resulting in 12 divisions with high economic disadvantage and low enrollment rates. These included Accomack County, Buckingham County, Charles City County, Colonial Beach, Cumberland County, Greensville County, Hopewell City, Northampton County, Petersburg City, Richmond City, and Westmoreland County. Surprisingly, the highest need for access to resources was found in the urban areas of Central Virginia (Corning et al., 2017). Policymakers should consider findings such as these when establishing local state STEM policies.

In sum, the literature in this section revealed important distinctions between urban and rural areas. Large urban areas appeared to be mostly disadvantaged in terms of providing equitable STEM education for their diverse populations (Cessna et al., 2018; Hill et al., 2018; Johnson & Sondergeld, 2020; Schreffler et al., 2019; Seals et al., 2017). Smaller rural areas, on the contrary, appeared to be disadvantaged with the lack of resources and technologies for STEM learning (Hill et al., 2018; Jarvis, 2018; Thomas & Falls, 2019; Tyler-Wood et al., 2018). The literature also addressed differences in state policies, highlighting certain states with established STEM policies such as Texas and North Carolina (Means et al., 2017; Saw, 2018). Virginia, which was the focus of the present study, was noted to have STEM initiatives that aimed to improve K-12 STEM education in preparation for college and the workforce (Kinoshita, 2020); however, certain issues in Virginia’s STEM education were highlighted, such as the issue of self-segregation, leading to inequitable opportunities (Neal, 2019). Notably, the literature surrounding STEM education in Virginia was significantly lacking in terms of how STEM is integrated in its schools. This calls for greater scrutiny regarding the local school division STEM policy in Virginia and whether these policies are reflected in practice.

Summary

This chapter contained a review of the literature relevant to the topic of local STEM education and policy. Several issues were noted in the literature such as the lack of a standardized definition for integrated STEM, the need for professional development for educators, inequitable opportunities for STEM learning, and other disadvantages related to locale categories. The literature also presented certain recommended practices such as the establishment of STEM-focused schools, school partnerships with other institutions and informal learning settings, and state-wide initiatives. Overall, the findings from the literature reflected a period of transition for integrated STEM education. As such, there is a need to examine how integrated STEM education is being developed at state-level and how state policies are being informed. Chapter 3 includes a discussion of how the present study aimed to fill this gap with the selected methodology.

Definition of Terms

21st Century Competencies – The competencies that need to be developed in 21st century students to succeed in the workforce includes character, citizenship, communication, collaboration, creativity, and innovation (Widya et al., 2019).

Career and Technical Education (CTE) – CTE tracks or programs involve the cultivation of career-oriented skills and knowledge, developing students’ employability, critical thinking, problem solving, and communication skills (Rosen et al., 2018).

Integrated STEM – There remains to be a universally accepted definition of integrated STEM in the literature; however, commonalities between various definitions include the use of real-world contexts, explicit connections between the four disciplines of STEM, career-oriented education, and student-centeredness in the form of problem-solving approaches (Ring et al., 2017).

Rural setting – Based on the National Center for Education Statistics (NCES), rural areas are classified into three possible codes depending on their distance to urbanized areas or urban clusters. Rural fringe areas are closest with five miles or less from an urbanized area or 2.5 miles from an urban cluster. Rural distant areas are between five and 25 miles from an urbanized area or between 2.5 to 10 miles from an urban cluster. Finally, rural remote areas are more than 25 miles from an urbanized area or more than 10 miles from an urban cluster (NCES, n.d.).

Urban schools – Urban schools contain a large population of diverse students, including many English language learners, poorer students, and racial minorities (Seals et al., 2017).

Chapter 3: Research Methodology

This chapter provides a detailed review of research methodology that was used to collect, analyze, and interpret data for this study. A description of the research design, population, instrumentation, procedures, analysis of data, and limitations of the study are given. The study investigated the local school division STEM policy and practice in Virginia determining how the school divisions have defined STEM education. Therefore, data were collected to address the research questions:

RQ1: Does the local school division have a definition of STEM education?

RQ2: If a school division has a definition of STEM education, does the definition employ the disciplinary definition or the integrated description of STEM education?

RQ3: Is there evidence in the school division that the STEM education activities are embedded in the school curriculum or part of the after school and extracurricular activities?

RQ4: Does the school division have a STEM for ALL approach or strategy to increase representation of gender, minorities, or students with disabilities in STEM?

Research Design

An exploratory mixed-methods research design was used in this study. The mixed-methods design combines both the qualitative and quantitative research techniques, approaches, methods, concept, and language in one study. According to Creswell and Clark (2011), the mixed-methods approach appeals well to versatility at the general, procedural, and practical levels. At the general level, mixed-methods research draws on qualitative measures and quantitative research. At the practical level, the approach appeals to the researcher as the novel procedure while, at the procedural level, it provides the underpinning or comparing perspectives that are drawn from both the qualitative and quantitative data analysis. Further, at the procedural level, it explains the quantitative results with qualitative data and explores the qualitative data to inform the quantitative data collection instruments. In addition, it helps the researcher to understand the results through perspective of participants within the systems. It has a broader perspective for the specific reasons for a needed intervention and offers a more comprehensive view of the necessary change. Therefore, the current research study adopted the procedural level of mixed-methods research to collect quantitative and qualitative data, integrate it, and use parallel design (Creswell & Clark, 2011). The mixed-methods research design was used in this study to examine various elements of a concept using different methods.

Content analysis is a methodology utilized in making valid inferences from texts, which could include texts from visual media. It is frequently done using a quantitative approach, particularly through counting word occurrences. One advantage of using content analysis is that it is impossible to contaminate data during the data collection process. For quantitative data, content analysis was considered. It is an evaluation device employed to find the presence of concepts, themes, and words within quantitative information such as text data (Xie et al., 2019). Through applying content analysis design, investigators can quantify and examine the occurrence, meanings, and associations of such notions, themes, and words. Investigators can further make conclusions concerning the information within the audience, writer, texts, as well as the time and culture related to the text (Xie et al., 2019). Quantitative content evaluation is not a novel technique in textual examination, as it has been widely adopted in fields such as social and health science as well as in education to appraise different statutes (Siraj & Fayek, 2019). The approach is mainly adopted to appraise policy topics through newspaper articles, technical reports, and expert interviews.

The content analysis further designates a set of techniques for systematic assessment of texts. Quantitative content evaluation is the close, inclusive, and orderly reading of a cluster of texts to determine patterns, intent, concepts, and themes. The technique of content analysis should not be confused as a mere counting of words because it entails the close reading of information with a focus on the study questions (Horne et al., 2020). The aim of undertaking a content analysis is to purposefully choose words to determine subjects or coding frames that are the main instruments to organize quantitative information into groups. All texts are evaluated closely and line by line by the investigators for a better comprehension of the information (Horne et al., 2020). Quantitative content analysis is further based on empirical content as opposed to the interpretive argument.

After conducting the content analysis of the school division websites, STEM descriptions, and plans, follow-up interviews were conducted to obtain more qualitative information from the STEM leaders and others who worked closely with STEM initiatives in the school divisions. Interviews were transcribed and analyzed for similar language and themes (Horne et al., 2020). The interview language was then paired with the themes identified in the website review. The pairing of this information provided a more complete picture of the landscape of STEM education in Virginia. It was informative to examine the public facing website review and description of activities with the more personal stories of actual implementation and practice to determine whether they were similar or different in nature.

Population and Setting

The targeted population for the study comprised all 132 school divisions in Virginia. No sample was calculated because the entire population of school divisions in Virginia was scrutinized. Follow-up interviews were conducted with a sample of five of the school division’s

STEM leadership who had knowledge of the STEM K-12 implementation. The reason for selecting this population was because the study sought to evaluate the local school division STEM education landscape in Virginia. The primary instrument used in collecting the essential information was the existing school divisions' websites. To capture the full picture of the state of STEM education in Virginia schools, it was important to evaluate all the locales for content analysis. As described in the VDOE website, there are 132 school divisions in Virginia. The school divisions were then reported by the eight superintendent regions and broken into their localities. These eight superintendent areas include central Virginia, Tidewater, Northern Neck, Northern Virginia, Valley, Western Virginia, Southwest, and Southside (VDOE, 2020). These regions were analyzed distinctively, and then the outcomes of one area were compared to those of the others. Additional comparisons of the school divisions by the size of the divisions and urban versus rural versus suburban divisions to determine whether and how each locality described their STEM education program.

Recruitment for the interviews consisted of identification of school division leaders with knowledge of STEM for their division. These names and emails were primarily collected from the VDOE website which lists contacts by school division. An initial email went out requesting interview participation with a description of the study. Additional emails were sent with a request to participate in the interviews. Only a few people responded even after multiple email attempts and follow up phone calls and messages. For those that expressed interest a digital interview was scheduled via the Zoom platform and calendar invitation was sent. Multiple attempts were made to reschedule one of the participant interviews but ultimately it was never completed due to conflicts. There was some delay in the interviews in the hopes that once the impacts of the pandemic subsided there would be more interest in participation but ultimately recruitment during this time was a challenge. Interviews were ultimately conducted with STEM leaders in two large suburban, one midsize city, one small city, and one small suburban school divisions. In addition to the size of the divisions for the follow-up interviews, specific care was taken to choose locales that represent diverse geographic regions of the state as well as urban, rural, and suburban districts, but ultimately, the participants were chosen by their willingness to voluntarily participate. Represented with interviews were school divisions located in Superintendent regions: 1- Central Virginia, 4- Northern Virginia, 5-Valley, and 7-Southwest. For clarity purposes the City of Fairfax schools has its own website, which was reviewed independently but functions as part of the Fairfax County schools with regards to NCES reporting. All the interview participants were working at the district level on STEM initiatives. Three of the five were housed in the school division central office. Two participants were based in schools, one of the school-based participants was in an elementary setting, and the other was in a high school setting. Depending on the setting and size of the school division some participants focused solely on Science or STEM and others had additional work assignments.

Instrumentation

Both quantitative and qualitative data were gathered in the study. Specifically, it was noted if the school divisions in Virginia have definitions of STEM education. For the divisions that had defined STEM education, the subsequent appraisal was based on the precise STEM education definition each division has adopted. Initially the VDOE website was used for gathering the URLs for all 132 school divisions. In this site, VDOE provided links to all the 132 school divisions' websites. From there, it was easy to access every website of each school district. Examples of other areas related to the STEM programs that were investigated were within webpages, posts, flyers, course catalogs, school budgets, and policy documents that came from search engine hits on the school division website as well as social media posts that appeared embedded in the website news feeds. Second, interviews were conducted with five school divisions' leaders with knowledge of the STEM programming. This allowed for more qualitative data to answer the research question regarding STEM practice and implementation.

Table 1 depicts the coding agenda for STEM information search on the school division website. The coding agenda was used closely to determine which school divisions have defined and implemented STEM education policy and the precise descriptions used as well as those that have not adopted this statute. The search also revealed the type of documents and communication each school division has published about STEM in their district.

Table 1

The Coding Agenda for the STEM Education Definition

Classification	Description	Coding guidelines
STEM	Science, technology, engineering, and mathematics	Adopted when four STEM areas are outlined alone.
STEM-ED	Science, technology, engineering, and mathematics in trans-disciplinary or interdisciplinary roles	Applied when a minimum of two STEM fields are outlined with phrases such as trans-disciplinary, integrated, combined, authentic learning, and problem-solving learning and interdisciplinary.
Both STEM descriptions	STEM and STEM-ED defined academic programs in the division.	Applied when both STEM and STEM-ED are mentioned in the evaluated documents.
STEM-IN	STEM education is embedded in the school curriculum.	Used when the STEM education activities are embedded in the school curriculum
STEM-Out		Used when the STEM activities are part of the after school and extracurricular activities
No STEM description	STEM education policy was not defined as an interdisciplinary technique of acronym.	Adopted when only the STEM acronym was used in media sources only.

Procedure

The data collection process entailed searching for relevant terms and phrases on each website of the 132 school divisions. All websites of these divisions were accessible from the VDOE site. Searches were further done from the division website and general Internet browsers. From the divisions' websites, the phrases that were used for searching included "STEM," "STEM education," and "STEM education policy," "STREAM, "STEAM," and "STEM-H." The search phrases used while searching from the VDOE website and general Internet browsers included “<<Virginia>> STEM education,” and “STEM education policy.” The idea behind these searches was to find documents and materials that led me to determine the execution of STEM education practice in all school districts in Virginia.

The analysis was accomplished in three phases. The initial phase was to gather the information to be evaluated based on the research questions. This phase entailed outlining qualitative data and whether phrases, words, and subjects linked to STEM education definitions existed on the school division website. If it was present and the documents accessible via the website, the URL was cataloged in a spreadsheet. The second stage involved comprehensively examining the documents to generate pertinent themes that are linked to the research questions. The third step was linking the identified themes to the research questions and analyzing the data. An Excel spreadsheet was used to summarize and organize the information found on the websites.

The information that was collected from the website review was organized into a spreadsheet that was then sorted according to Superintendent Region, the size of the school division, as well as the NCES locale designation (VDOE, 2020). Table 2 provides the NCES classification definitions and corresponding locale codes. The spreadsheet served as a collection of links to artifacts such as the school division websites, calendars, strategic plans, budgets, and program of studies. If a STEM plan existed, a link was also copied into the spreadsheet. A search for “STEM” was conducted on the home page of the school division’s website, and the number of search hits was recorded. Search hits was defined as the number of results the search engine returns in response to the word “STEM.”

Table 2

NCES Locale Classifications and Criteria

NCES locale code	NCES locale	Definition
City	Large	Territory inside an urbanized area and inside a principal city with population of 250,000 or more.
	Midsize	Territory inside an urbanized area and inside a principal city with population less than 250,000 and greater than or equal to 100,000.
	Small	Territory inside an urbanized area and inside a principal city with population less than 100,000.
Suburban	Large	Territory inside an urbanized area and inside a principal city with population less than 100,000.
	Midsize	Territory outside a Principal City and inside an Urbanized Area with population less than 250,000 and greater than or equal to 100,000.
	Small	Territory outside a Principal City and inside an Urbanized Area with population less than 100,000.
Town	Fringe	Territory inside an Urban Cluster that is less than or equal to 10 miles from an Urbanized Area.
	Distant	Territory inside an Urban Cluster that is more than 10 miles and less than or equal to 35 miles from an Urbanized Area.
	Remote	Territory inside an Urban Cluster that is more than 35 miles from an Urbanized Area.
Rural	Fringe	Census-defined rural territory that is less than or equal to 5 miles from an Urbanized Area, as well as rural territory that is less than or equal to 2.5 miles from an Urban Cluster.
	Distant	Census-defined rural territory that is more than 5 miles but less than or equal to 25 miles from an Urbanized Area, as well as rural territory that is more than 2.5 miles but less than or equal to 10 miles from an Urban Cluster.
	Remote	Census-defined rural territory that is more than 25 miles from an Urbanized Area and also more than 10 miles from an Urban Cluster.

Note. Source: NCES locale classifications and Criteria. https://nces.ed.gov/programs/edge/docs/LOCALE_CLASSIFICATIONS.pdf

The website review initially began in the winter of 2020 and continued through summer of 2022. It should be noted that this was spread out over a longer period than originally intended but in the hope that the impacts of COVID-19 might be reduced on the activities that existed in the school divisions. There is some certainty that a decrease in the amount of published extracurriculars occurred during the 2021-22 school year due to the pandemic. Depending on the school division, most student learning occurred in person by the spring of 2021, with a hybrid option available. There were also serious disruptions that continued throughout the school year due to COVID-19 infections, exposure, and quarantine periods. A brief follow-up sampling of data was done in late summer of 2022, and there were no noticeable changes when comparing the data from websites analyzed in 2021. Future research may observe an increase in activities now that the impact of the pandemic has decreased and there are more in-person activities.

Interviews were conducted after the website analysis. The original intent was to select three small, three medium, and three large school divisions for follow-up interviews. Specific geographic regional and superintendents' regions were also considered to provide representation from different superintendent regions of the Commonwealth. Some time elapsed trying to recruit participants with email outreach and phone calls. Ultimately, the school divisions' leaders who responded to email and follow-up requests were chosen to be interviewed. One interview was scheduled but cancelled and rescheduled multiple times and ended up not being done due to concerns about the research policy procedure within the district. Requests for the interviews were made to the STEM coordinator or whoever was identified as the person responsible for or related to STEM education. Contact information was provided for each school division on the VDOE website. Questions were presented on presentation slides during a virtual meeting using the Zoom platform. The interviews were recorded and transcribed using a software program called Grain.

Data Analysis

Data were analyzed both qualitatively and quantitatively. For qualitative data undergoing content analysis, a thematic evaluation was employed to evaluate the research data, where school divisions with common patterns and themes on the definition and specification of STEM education policy and practice were categorized together. There were six categories encompassing STEM education definitions: STEM, STEM-ED, Both STEM descriptions, STEM-IN, STEM-out, and No STEM description. Other themes including diversity themes encompassing SWDs, minorities, and gender were also explored. This included embedded versus extracurricular in the STEM set ups. Finally, the evaluation was made on whether STEM is primarily integrated or disciplinary. The significance of implementing thematic analysis was to compress the big quantities of qualitative data to significant themes, subjects, and trends (Braun & Clarke, 2019). The information was evaluated for noteworthy words, statements, and phrases from each website and the interview participant to determine the emerging patterns, themes, and subjects while provided the information on the definition of STEM education initiatives in school divisions in Virginia. After concepts, subjects, and trends were determined, solid themes were described based on the prominence of the research questions.

Limitations

The description of STEM education is continuously evolving as policymakers change the landscape frequently. As a result, searches over the Internet might not yield the most recent and updated documents on STEM education practice for each school division. Further, collecting the data over Internet sources may not guarantee the precision of the findings. Also noted was that some school divisions have insufficient documents linked to their websites to evaluate the research questions on STEM education policy and practice. The study did not always find adequate sources and documents linked to the searches, “STEM education” and “STEM education policies.” While this is a limitation of the study, a school division that lacks any mention of STEM to their outward facing website is also worthy of notation.

Another major limitation of the study was that many of the STEM coordinators simply did not reply and therefore refused to take part in the interview. The lack of response did deny the study a chance to have a more selective pool of participation in the interviews. This study was also conducted while many school divisions had pivoted to focus on distance learning and were dealing with many other nontraditional issues brought on by the ongoing COVID-19 pandemic. Thus, it is difficult to know how many more may have participated in more traditional school years. Execution of STEM education might also differ because of distance learning as well as the regional or local area primacies like county laws, curriculum models, and available resources. For some divisions, particularly those that struggle with school funding shortages, staffing issues, and those in more remote or disadvantaged regions, the execution of STEM education and practice can be seen as more difficult because it necessitates a broad range of space, instructors, and supplies.

Summary

The research design utilized in this study was the exploratory mixed-methods for both qualitative and quantitative data. Qualitative analysis is an assessment device employed to find the presence of concepts, themes, and words within qualitative information, such as text data. The targeted population for the study comprised all 132 school divisions in the Commonwealth of Virginia. The entire population was analyzed. The primary instrument that was used in collecting the required data was the VDOE website which links to all of Virginia school divisions as well as identifying key personnel at each. The other key instrument was the coding agenda for the usage of STEM education documents and descriptions. The agenda was implemented closely to determine school divisions which have defined and implemented STEM education and the precise descriptions used as well as those that have not adopted this statute. The coding guidelines focused on whether the distinct fields of STEM, Science, Technology, Engineering, and Math were integrated or presented primarily in isolation of the others. Division leaders with knowledge of the STEM programing in their respective districts were interviewed and the responses analyzed for trends and themes. Thematic evaluation was used to assess the study information, where school divisions with common patterns and themes on the definition and specification of STEM education policy and practice were categorized together. Chapter 4 includes a presentation of the data analysis and the results of the study.

Chapter 4: Results

This mixed-methods research study examined the local school division STEM policy and practice in Virginia to synthesize an effective STEM education strategy that warrants policy and funding supports. Using the 132 school divisions of Virginia Department of Education and follow-up interviews, it sought to answer the following research questions:

RQ1: Does the local school division have a definition of STEM education?

RQ2: If a school division has a definition of STEM education, does the definition employ the disciplinary definition or the integrated description of STEM education?

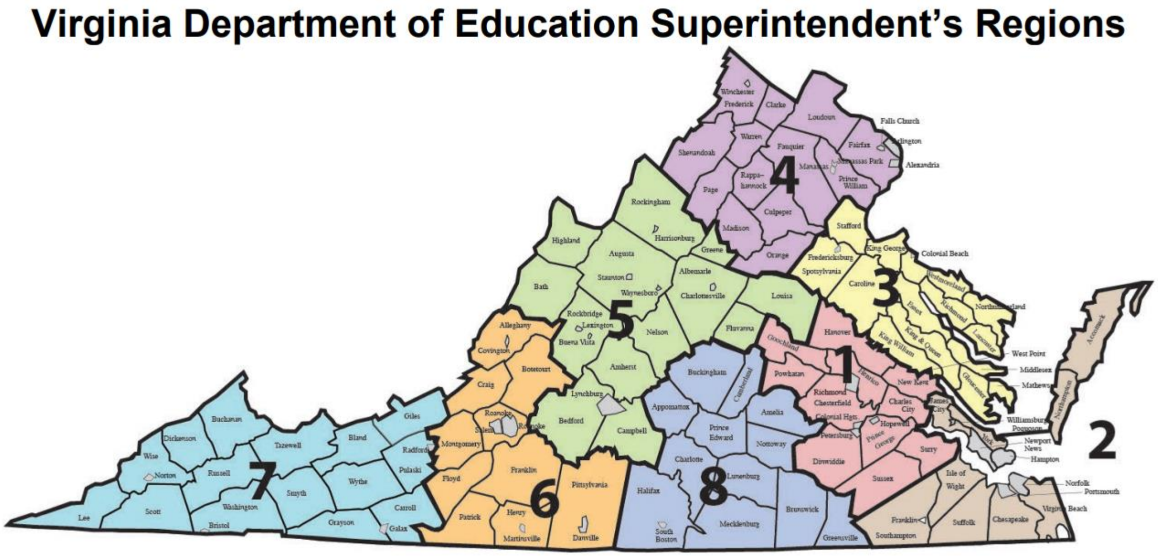
RQ3: Is there evidence in the school division that the STEM education activities are embedded in the school curriculum or part of the after school and extracurricular activities?

RQ4: Does the school division have a STEM for ALL approach or strategy to increase representation of gender, minorities, or students with disabilities in STEM?

This chapter details the results from the data analysis procedure that was adopted to collectively understand the policy and practice of educators in the implementation of STEM in Virginia. Answers to the research questions of the study are reported within the context of present data and past literature. The chapter ends with a summary of the study. For reference purposes Figure 2 shows a map of Virginia's school divisions separated into the eight defined superintendent regions that are mentioned throughout the chapter.

Figure 2

Virginia Department of Education Superintendent's Regions



Data Analysis

The information that was collected from the website review was organized into a spreadsheet that was sorted according to Superintendent Region, the size of the school division, as well as the NCES locale designation (VDOE, 2020). The content was then reviewed, analyzed, and information related to the research questions was recorded. Similar terms such as STEAM, STREAM, and STEM-H were also included in the analysis. Tables 3 to Tables 8 show the website evaluation results. The tables provide a summary of the results of STEM evaluations by region in terms of NCES locale, NCES size, STEM search hits, whether STEM was defined, and if there were Out of School Time (OST) activities listed on the website.

Table 3

Region 1. STEM Evaluation Results Via Website

Division name *N* = 15	NCES locale	NCES size	STEM search hits	STEM defined (Y/N)	OST activities listed on website
Charles City County	Rural	Distant	3	No	No
Chesterfield County	Suburb	Large	10	No	Yes
Colonial Heights	Suburb	Large	1	No	No
Dinwiddie	Rural	Distant	35	No	Yes
Goochland County	Rural	Distant	889	Yes	No
Hanover County	Suburb	Large	9	No	No
Henrico County	Suburb	Large	3	No	No
Hopewell	Suburb	Large	14	No	Yes
New Kent County	Rural	Distant	1	No	Yes
Petersburg	Suburb	Large	10	No	Yes
Powhatan County	Rural	Distant	5	No	No
Prince George County	Rural	Fringe	3	No	No
Richmond	City	Midsize	1870	Yes	No
Surry County	Rural	Distant	7	No	No
Sussex County	Rural	Distant	25	No	No

Table 4

Region 2. STEM Evaluation Results Via Website

Division name *N* = 15	NCES locale	NCES size	STEM search hits	STEM defined (Y/N)	OST activities listed on website
Accomack County	Rural	Remote	96	Yes	No
Chesapeake	Suburb	Large	754	No	No
Franklin	Town	Distant	44	No	Yes
Hampton	City	Midsize	259	No	Yes
Isle of Wight County	Rural	Fringe	20	No	No
Newport News	City	Midsize	874	Yes	No
Norfolk	City	Midsize	2740	Yes	No
Northampton County	Rural	Remote	1	No	No
Poquoson	Suburb	Large	903	No	No
Portsmouth	City	Small	50	No	Yes
Southampton County	Rural	Distant	35	No	No
Suffolk	Suburb	Large	3	No	Yes
Virginia Beach	City	Large	55	Yes	No
Williamsburg James City County	Suburb	Small	456	Yes	Yes
York County	Suburb	Large	183	No	Yes

Table 5

Region 3. STEM Evaluation Results Via Website

Division name *N* = 17	NCES category	NCES size	STEM search hits	STEM defined (Y/N)	OST activities listed on website
Caroline County	Rural	Distant	831	Yes	Yes
Colonial Beach	Town	Distant	2	No	No
Essex County	Town	Distant	2	No	Yes
Fredericksburg	Suburb	Midsize	131	No	Yes
Gloucester County	Rural	Fringe	135	No	No
King George County	Town	Distant	10	No	Yes
King William County	Rural	Distant	0	No	No
King and Queen County	Rural	Distant	10	No	No
Lancaster County	Rural	Remote	1		No
Mathews County	Rural	Distant	0	No	No
Middlesex County	Rural	Distant	0	No	No
Northumberland County	Rural	Distant	3	No	No
Richmond County	Town	Distant	19	No	Yes
Spotsylvania County	Suburb	Midsize	79	No	Yes
Stafford County	Suburb	Large	1520	Yes	Yes
Westmoreland County	Rural	Distant	1	No	No
West Point	Town	Fringe	6	No	No

Table 6

Region 4. STEM Evaluation Results Via Website

Division name *N* = 20	NCES category	NCES size	STEM search hits	STEM defined (Y/N)	OST activities listed on website
Alexandria	City	Midsize	907	Yes	No
Arlington County	City	Midsize	2640	Yes	Yes
Clarke County	Town	Fringe	8	Yes	Yes
Culpeper County	Town	Distant	0	No	Yes
Fairfax City	NA	NA	1	No	Yes
Fairfax County	Suburb	Large	184	Yes	No
Falls Church	Suburb	Large	2	No	No
Fauquier County	Suburb	Large	200	No	Yes
Frederick County	Rural	Fringe	7	No	Yes
Loudoun County	Suburb	Large	9620	Yes	No
Madison County	Rural	Distant	3	No	Yes
Manassas	Suburb	Large	1200	Yes	Yes
Manassas Park	Suburb	Large	51	No	Yes
Orange County	Town	Distant	39	No	No
Page County	Rural	Distant	26	No	No
Prince William County	Suburb	Large	1470	Yes	Yes
Rappahannock County	Rural	Distant	1	No	Yes
Shenandoah County	Town	Distant	2	No	No
Warren County	Town	Fringe	0	No	No
Winchester	City	Small	401	Yes	No

Table 7

Region 5. STEM Evaluation Results Via Website

Division name *N* = 20	NCES locale	NCES size	STEM search hits	STEM defined (Y/N)	OST activities listed on website
Albemarle County	Rural	Fringe	174	No	No
Amherst County	Rural	Fringe	3	No	No
Augusta County	Rural	Fringe	68	No	No
Bath County	Rural	Remote	19	No	No
Bedford County	Rural	Fringe	1	Yes	No
Buena Vista	Rural	Fringe	0	No	No
Campbell County	Rural	Fringe	12	Yes	Yes
Charlottesville	City	Small	74	Yes	No
Fluvanna County	Rural	Distant	5	No	No
Greene County	Town	Fringe	52	No	No
Harrisonburg	City	Small	33	Yes	No
Highland County	Rural	Remote	14	No	No
Lexington	Town	Distant	0	No	No
Louisa County	Rural	Distant	0	No	No
Lynchburg	City	Small	52	No	No
Nelson County	Rural	Distant	3	No	No
Rockbridge County	Town	Distant	19	No	No
Rockingham County	Rural	Fringe	11	No	Yes
Staunton	City	Small	104	No	No
Waynesboro	Suburb	Small	0	No	No

Table 8

Region 6. STEM Evaluation Results Via Website

Division name *N* = 15	NCES locale	NCES size	STEM search hits	STEM defined (Y/N)	OST activities listed on website
Alleghany County	Rural	Fringe	3	No	No
Botetourt County	Rural	Fringe	0	No	No
Covington	Town	Distant	0	No	No
Craig County	Rural	Distant	0	No	No
Danville	Town	Distant	0	No	No
Floyd County	Rural	Distant	22	No	No
Franklin County	Town	Distant	4	No	No
Henry County	Rural	Fringe	19	No	No
Martinsville	Town	Distant	30	No	No
Montgomery County	City	Small	2	No	No
Patrick County	Rural	Distant	0	No	No
Pittsylvania County	Rural	Distant	14	Yes	No
Roanoke	City	Small	7	No	No
Roanoke County	suburb	Small	69	No	No
Salem	suburb	Midsize	6	No	Yes

Table 9

Region 7. STEM Evaluation Results Via Website

Division name *N* = 19	NCES locale	NCES size	STEM search hits	STEM defined (Y/N)	OST activities listed on website
Bland County	Rural	Distant	2	No	No
Bristol	Suburb	Small	18	No	No
Buchanan County	Rural	Remote	4	No	No
Carroll County	Rural	Distant	7	No	No
Dickenson County	Rural	Remote	0	No	Yes
Galax	Town	Remote	0	No	No
Giles County	Town	Distant	4	No	No
Grayson County	Rural	Remote	3	No	No
Lee County	Rural	Distant	0	No	No
Norton	Town	Distant	5	No	No
Pulaski County	Rural	Fringe	53	No	No
Radford	Suburb	Small	40	No	No
Russell County	Rural	Distant	0	No	No
Scott County	Suburb	Midsize	0	No	No
Smyth County	Rural	Fringe	5	No	No
Tazewell County	Town	Distant	81	No	Yes
Washington County	Rural	Fringe	33	No	No
Wise County	Town	Distant	48	No	No
Wythe County	Rural	Distant	0	No	No

Table 10

Region 8. STEM Evaluation Results Via Website

Division name *N* = 12	NCES locale	NCES size	STEM search hits	Stem defined (Y/N)	OST activities listed on website
Amelia County	Rural	Distant	5	No	Yes
Appomattox County	Rural	Distant	0	No	No
Brunswick County	Rural	Fringe	6	No	Yes
Buckingham County	Rural	Remote	1	No	No
Charlotte County	Rural	Remote	1	No	No
Cumberland County	Rural	Remote	47	No	Yes
Greensville County	Town	Distant	2	No	No
Halifax County	Town	Remote	0	No	No
Lunenburg County	Rural	Remote	46	No	No
Mecklenburg County	Rural	Fringe	20	No	No
Nottoway County	Rural	Distant	0	No	No
Prince Edward County	Town	Remote	10	Yes	No

Table 11

Study Population NCES Classification

Region	Number of School Divisions	Rural 49%	Suburb 20%	City 11%	Town 20%
Region 1 Central Virginia	15	8	6	1	0
Region 2 Tidewater	15	4	5	5	1
Region 3 Northern Neck	17	9	3	0	5
Region 4 Northern Virginia	19	4	7	3	5
Region 5 Valley	20	12	1	4	3
Region 6 Western Virginia	15	7	2	2	4
Region 7 Southwest	19	11	3	0	5
Region 8 Southside	12	9	0	0	3
Totals	132	64	27	15	26

STEM Search Results

The NCES designations for the school divisions were broken down into 15 city, 64 rural, 27 suburb, and 26 town, Table 11 summarizes these distinctions by superintendent region. STEM search hits, defined as the number of results the search engine returns in response to the word "STEM," on the school division websites ranged from 0-9620, demonstrating that there was a great deal of variability about the information to be found just using the website as a primary tool for gathering data. There were 23 school division websites that had zero search hits with STEM, or about 17% of the sample. Of the 23 divisions with no STEM search hits, 21 (91%) had a rural or town NCES locale distinction and two (9%) were suburbs. Sixty school divisions or 45% of the total number had at least one STEM search but had less than 20 hits. There were 26 divisions, or 20% of the total, that had between 21-104 STEM search hits. There were 15 school divisions, or 11%, that had between 104-907 search hits. There were seven school divisions that had over 1,000 STEM search hits on their website. Out of the seven with the most STEM search hits, four were large suburban and three were midsize city divisions. Loudoun County had the most STEM search hits, with 9,620 hits, which far surpassed the other divisions. Table 12 displays the districts with no search hits on their websites. It should be noted that just because they did not mention it via the website there could still be STEM activity occurring. Table 13 and Figure 3 show the number of STEM search hits by region. In going through the STEM hits, it was noted whether the descriptions of activities were embedded in the school day or listed as an out of school time activity or enrichment program. This was noted as STEM-In for during the school day and STEM-Out for out of school time, BOTH was used to denote descriptions of activities that occurred both in and out of school times. The most frequent mention of STEM activity on the websites were robotics clubs or competitions, STEM fairs or STEM showcase nights, STEM camps or enrichment opportunities, and STEM awards or scholarships announcements. A description of activities that were geared towards girls or minorities were often in the form of flyers announcing student opportunities to participate with local business and industry or higher education programs.

Table 12

School Divisions with Zero STEM Search Hits on Website by Superintendent Region

Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	Region 7	Region 8
None	None	King William Matthews Middlesex	Culpeper Warren	Buena Vista Lexington Louisa Waynesboro	Botetourt Covington Craig Danville Patrick	Galax Lee Russell Scott Wythe	Appomattox Halifax Nottoway

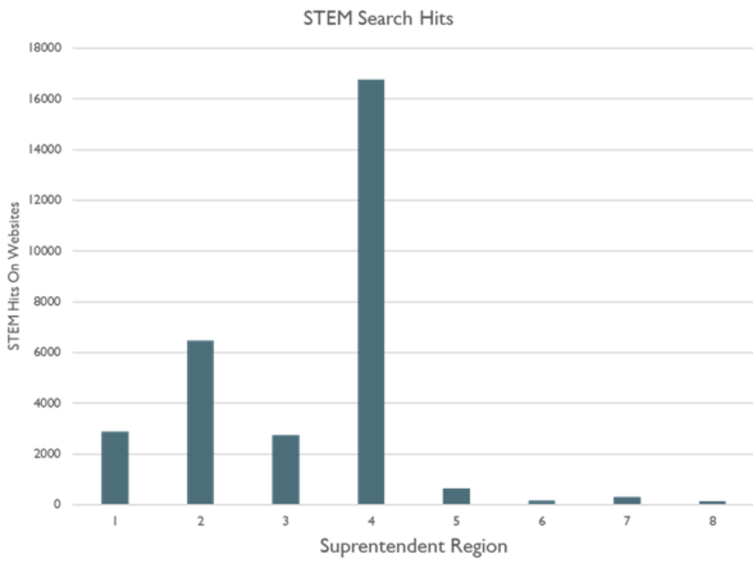
Table 13

STEM Search Hits

Region	STEM search hits
1	2885
2	6473
3	2750
4	16762
5	644
6	176
7	303
8	138

Figure 3

STEM Search Hits



Research Question 1

Research question 1 asked, does the district have a STEM definition? Table 14 shows school division by region that had a STEM definition on the website. It also lists NCES classification and if the division listed both in and out of school activities or both.

Table 14

School Division by Region With A STEM Definition on Website

Region	Division	NCES category	NCES size	Classification	STEM in or out
1	Goochland	Rural	Distant	STEM-ED	Both
1	Richmond	City	Midsize	STEM-ED	Both
2	Accomack	Rural	Remote	STEM-ED	Both
2	Newport News	City	Midsize	STEM-ED	IN
2	Norfolk	City	Midsize	STEM-ED	IN
2	Virginia Beach	City	Large	STEM-ED	IN
3	Caroline	Rural	Distant	STEM	Both
3	Stafford	Suburb	Large	STEM-ED	IN
4	Alexandria	City	Midsize	STEM-ED	Both
4	Arlington	City	Midsize	STEM-ED	Both
4	Clarke	Town	Fringe	STEM-ED	IN
4	Fairfax	Suburb	Large	STEM-ED	Both
4	Loudoun	Suburb	Large	STEM-ED	Both
4	Manassas*	Suburb	Large	STEM-ED	Both
4	Prince William	Suburb	Large	Both	Both
4	Winchester	City	Small	Both	Both
5	Bedford	Rural	Fringe	STEM	In
5	Campbell	Rural	Fringe	STEM-ED	In
5	Charlottesville	City	Small	Both	Both
5	Harrisonburg	City	Small	STEM-ED	Both
6	Pittsylvania*	Rural	Distant	STEM	In
8	Prince Edward	Town	Remote	STEM-ED	Both
8	Williamsburg-James City	Suburb	Small	STEM-ED	Both

Note. *Denotes the division addressed diversity or a STEM for all approach in their descriptions.

A review of 132 school divisions was done to determine whether a STEM definition existed in a public facing document that is searchable from the school division website. This was recorded as a simple yes/no on the spreadsheet. It was found that 16% (n = 21) of the school divisions had a definition on their website. Of the school divisions that had a clear definition of STEM on their website, 43% were classified as city schools, 24% were suburban schools, 24%

were rural schools, and 9% were classified as town using the NCES categories. This means that 84% of the school divisions did not have a definition on their website.

Theme 1: Existence of Sense-Making Definition of STEM

The review further found how the STEM definition resonates among Virginia educators from the perspectives of the five participants who identified themselves as highly engaged in their divisions' STEM programs. Using content analysis, it was identified "Existence of sense-making definition of STEM" as a theme to describe the collection of responses from the five participants of the study. All participants acknowledged the existence of STEM definition and claimed that the general definition is published in various education websites such as VDOE and Science educators' associations or government agencies. The definition on the VDOE website for STEM is provided in Chapter 1.

Participant 1 from region 1 stressed that for educators to implement STEM programs, educators must have the definition of a program they embraced. Participant 1 said, "We do technically, in order to be STEM it has to have three of the four (disciplines)." Participant 2 from region 4 stated, "I know it exists…but it's on the Virginia department of education website." Participant 3 from region 4 responded to this inquiry as, "Yes, we do, because we have a STEM plan. We have…a position,… a STEM coach." Participant 4 from region 5 claimed, "We use an integrative, is our definition, um, it is on our website." They went on to explain that the definition is included as part of all their professional development slides. Although Participant 5 from region 7 defined STEM as science, technology, engineering, and math, they stated that publication of the school concept and definition of STEM is "a work in progress."

While these participants claimed to have a STEM definition, there is still confusion about what STEM education is and what it entails in terms of curriculum and student outcomes.

Participant 1 shared a few of their observations among educators who claimed to have embraced STEM in their curriculum. Participant 1 said,

> It has to have three of the four *(disciplines)*, at the very least, if it just is a macaroni tower, that's not STEM, that's a teamwork project… an engaging activity, but that's not truly STEM. It's barely engineering, and it certainly is not a math or science.

They went on to say, "measuring the height of the tower, does not really count as math, you had at least had to do an average height of, or weight of, or the weight that it bears." Participant 2, on the other hand, believed only two of the four aspects in STEM stand out. They said, "I'm probably a bigger believer of making the T and E of STEM stand out. Um, technology and engineering are the two sorts of pathways through which math and science are given context." Participant 3 defined STEM as an integrative education plan that details the teaching strategies appropriate in helping students understand the concepts and purpose of STEM. Participant 3 described it as follows:

> It was really about how those constructs, or those different domains were integrated and working together. That was our definition of STEM, and helping students understand those concepts was part of the job description for our STEM coaches. Our STEM coaches would engage students differently at every school, but always with the purpose of doing cross curriculum sort of projects and looking at how science, technology, engineering, and math were evident and present in all of the things that we were doing in school.

The five responses illustrated how STEM education is considered as either a single or multidisciplinary field, but there is no consensus on the nature of the material and pedagogical interactions among the STEM domains. Participant 4 shared a minimal differentiation of what STEM is based on their experiences with the STEM program. Participant 4 viewed STEM as a single program integrating the STEM academic domains and explained that whereas science and mathematics education are well-defined yet distinct entities in elementary and secondary schools, engineering education has been primarily a function of higher education. When incorporated at all in secondary education, technology education has usually been relegated to vocational education. Participant 4 described this model as: “In (middle school), there is one teacher that is CTE certified in science, and they teach two classes. They teach a science class and “E” (engineering) class, but they're together.” They further described how STEM is integrated in the curriculum among students who are not in STEM courses in their secondary education: “We do offer engineering courses in non-STEM pathways, *We offer*….which is all about drones and, agriculture together, works really nicely with environmental science. We have students who are not in STEM *pathway*, can take dual enrollment engineering.”

Participant 5 described STEM in the context of policy additions that could improve the curriculum across grade levels. Participant 5 said, “*we added* computational thinking. We are beginning to add that component to our STEM program.” Participant 5 highlighted the complexity of incorporating STEM curriculum improvement. They discussed the significance of integrating activities utilizing a shared understanding of STEM across the system in order to design and implement curriculum and teaching that can support STEM learning success for all students more effectively. They explained,

> All of this is still kind of a work in progress. We are working right now on a curriculum, website that will be linked to our school system website that is, and it's got all of our curriculum on it, but it's got the computer science, digital learning, Project Lead the Way and, and all of that, because we look at all of that kind of as our STEM.

Research Question 2

Research question 2 asked, if a school division has a definition of STEM education, does it employ the disciplinary definition or the integrated description of STEM education? Of the 23 divisions that had definitions, three (13%) adopted the STEM definition where each four disciplines were outlined alone. An applied definition where a minimum of two STEM disciplines are outlined using phrases such as integrated, interdisciplinary, combined, authentic learning, and problem solving were used in 17 of the 23 divisions or 74% and labeled as STEM-ED. Three of the divisions (13%) used a combination of both STEM and STEM-ED descriptions. Only two of the divisions specifically included addressing diversity in STEM or a STEM for all approach. These were outlined in Table 13.

The analysis of interview data revealed various STEM experiences among educators, which were directed by school leaders who may have different interpretations of STEM education and STEM integration. The researcher identified the STEM experiences shared in the interview that reflect how STEM education has been defined variously ranging from disciplinary through to transdisciplinary approaches. These experiences were thematically grouped as Differentiated STEM Programs, which are discussed in this section.

Theme 2: Differentiated STEM Programs

With a lack of an agreed upon definition of STEM education, experiences of the participants to STEM activities vary from disciplinary to transdisciplinary approach to integration in the curriculum. Participant 1, for instance, shared that while there are efforts to integrate STEM across the school system, mainstreaming the integration of STEM across disciplines and levels are challenging. Participant 1 shared these sentiments:

> A middle school has a defined STEM semester elective. Those activities include a variety of things…by and large, it tends to be taught by science teachers. So they, they really, bring in the S to that. But depending on master scheduling, I have had CTE teachers, I've had GT teachers, I've had an English language arts teacher and a social studies teacher and a GT teacher teach that. They each bring a different thing into the giant Google drive folder of activities. They bring a different world view. You know what I mean? If you're an English language arts people, you know, you definitely see the world differently than I do. ….. theoretically, it’s just one time over the three years…..it’s so popular that we often have a waiting list for it.

Participant 2 also expressed the difficulty sustaining the integration of STEM across disciplines. Participant 2 shared, “It's supposed [to be] authentic learning experiences for all students enter disciplinary and applied approach. You're building on previous experience and feels connected.” Participant 2 believed that the integration’s complexity is so intricate that they had trouble comprehending it. Participant 2 said, “It's still to this day boggles the mind that we silo all our subjects so clearly defined. And yet don't acknowledge the connections between the two or between all of them.”

Participant 3 explained the differentiation of STEM programs through a comparison of the STEM curriculum in elementary, middle school, and high school. Participant 3 described the elementary STEM as more integrative “across all curricular areas” and slowly becomes an elective part of the curriculum in middle school and high school. Participant 3 justified that STEM in elementary must be authentic and purposeful and should served as an “early-stage support… that every learner is unique and has different strengths.” Participant 3 described that middle school should teach learners the application of the basic concepts and create their own concepts. Participant 3 described the STEM education objective in middle school:

> How do we get the kids from exploring what a tool can, how they can make a tool and what, and their impact that they can have on creating, um, something with purpose to then fast forward to seventh grade, where they literally are exploring alternative sources of energy and writing a proposal and a methodology section that talks about, what are the, who are our participants? What is our purpose? What is our, um, what's going to be, our variables are in, you know, they, they learn all about the scientific process.

In high school, Participant 3 described high school STEM as more applied than integrative curriculum. Learners in this stage elect specific discipline for their future professional career. Participant 3 described the focused of STEM in high school in the following manner:

> We're starting to really want the kids to start to identify, like, what are their interests and how might they leverage their talents and their strengths, and there's knowledge into a career that is portable, that is scalable, and that will let them be contributing members of society, which is part of our mission. Right. And that is all of these things are connected to something that we call the ideal graduate in Virginia.

Research Question 3

Research question 3 asked, are the STEM education activities embedded in the school curriculum or part of the after school and extracurricular activities? The website review revealed through the STEM search results that both embedded and OST activities exist within the school divisions in Virginia. Region 4 had the greatest amount of OST with 58% of their divisions having OST on the websites. Overall, a total of 37 school divisions have OST activities on websites for a total of 28% of schools. Most of the descriptions were media announcements about activities or contests that were shared via flyers and social media posts. Again, it is difficult to know how much impact COVID-19 had on those activities, as many of the websites had old posts from previous school years announcing STEM nights, competitions, and enrichment activities. It was simply documented as a Yes/No for each division if they described embedded or OST activities. No real calculation of how much time in each area was being addressed due to the differing levels of robust reporting of this information from website to website. There was not enough consistency between the school divisions to create a comparative analysis of time spent in each area.

The analysis of interview data revealed the evolving concepts of STEM integration across all levels in elementary and secondary education. All participants in the interview mentioned that STEM has produced new approaches to teaching and learning, and the topics have become more applied as learners get older. These experiences were thematically grouped as Scaling Embedded STEM Integration, which are discussed in this section.

Theme 3: Scaling Embedded STEM Integration

In contrast to traditional science, mathematics, and information technology lessons taught in elementary, the emphasis has changed from learning and regurgitating content in middle to secondary education to greater emphasis on the application of scientific knowledge, the acquisition of technological manufacturing skills, and design thinking. The scaling progression of STEM perspectives and approaches of educators are demonstrated in comparative views of STEM integration in elementary to high school curriculum. Participant 4, for instance, described how STEM integration is embedded in the curriculum from elementary to secondary school. Participant 4 used the computer science subject to demonstrate the embedding process in the following statement:

> We have embedded computer science into STEM units that we have in elementary. We've done the middle-school integration of Arduinos, uh, into some of our STEM units at the middle school. And, and this year I have a teacher who wants to do it in non-stem focused classes, eighth grade, some Arduino stuff, which we'll see how that goes. And then, um, we also have done a lot of integration. There's just a lot of integration of computer science in our engineering courses at the high school. So, we also have AP computer science and some other computer science classes that our STEM focused students are required to take at least one computer science class.

When asked whether STEM education activities are embedded in the school curriculum or part of the after school and extracurricular activities, Participant 5 responded, “they are embedded, our classroom teachers do it as well as we do it in our specialty classes.” Participant 5 further shared the innovation application program designed for high school students who may have the interest in pursuing STEM career. Participant 5 shared this experience as, “data supporting the need in our area where we are preparing students for jobs that require computer science skills and, and STEM occupations. We listed the STEM occupations and the projected job opportunities.”

Research Question 4

Research question 4 asked, does the school division have strategies to address diversity in STEM specifically for gender, minority, and students with disabilities being represented? There were a few mentions of women in STEM days or social media posts that called attention to diversity in STEM, but not enough data existed for this to be compared across the school divisions. Due to the lack of information posted on the websites, it should be noted that information regarding gender, minority, and students with disabilities was not comparable in the website review. It is not known if there is any standard of communication required on the school's web pages and this was noted as an area where improvement can be made in communication with students, families, and community stakeholders.

To better support learning settings that assist students to establish positive STEM identities, it is essential to understand how these identities are developed and nourished within formal education institutions. A review of the responses from the participants' interviews suggests the faculty and students' interest is a driver of success in gender and inclusion of STEM curriculum and activities. The descriptions of these views are discussed in this section.

Theme 4: Interest in STEM Drives Successful Inclusion of Gender, Minority, and Students With Disabilities

While all study participants asserted that school leaders had policies and budgets in place to encourage full participation in STEM programs, they were all in agreement that the success of the STEM curriculum, including its activities on and off campus, is largely dependent on the interests of the school divisions' stakeholders. Participant 4 said, "really interest is the biggest factor, they have to be interested." Participant 4 shared that without interest, learning can be difficult for both teachers and learners. Participant 4 further shared that while "make[ing] equity and accessibility for our students has been my primary focus over the years, resources are limited, and we could not afford continuously accommodating students with major discipline problems."

Participant 5 also claimed that the effort to reach out to involve the wider student population depends on their interest, which may not necessarily be aligned to their learning needs. Participant 5 compared the STEM interest between gifted advanced students and thriving students in this statement: "the students that thrive in this area (STEM) are those that have more learning needs… gifted and more advanced students… They don't like it, because they like cut and dried." This differentiated interest became one of the reasons for offering elective STEM subjects and activities in middle schools of Participant 1's school division. Participant 1 explained,

> You see our sample science pathways here…this is for secondary science and it is based on what math you're in…but there there's a couple of different pathways you can do. There is physics first option. It's not widely popularized, but that is an option. I do have some students who can potentially do that.

In the integration of more diverse STEM learners and teachers, Participant 3 also recognized a need to comprehend the teachers and learners' STEM-related interests. Participant 3 shared this sentiment:

> look at our academic pursuits in context, and not necessarily just as an academic pursuit…we're starting to really want the kids to start to identify, like, what are their interests and how might they leverage their talents and their strengths, and there's knowledge into a career that is portable, that is scalable, and that will let them be contributing members of society.

When Participant 5 was asked if there were barriers to prevent students from participating in STEM programs, they responded, "Just their desire that, I mean, I , I think we have enough resources that we could help with any other types of barriers that there might be."

Interest among educators for interdisciplinary STEM integration has also been identified as a barrier in the implementation of an inclusive STEM curriculum. Participant 2 shared, "a lack of interest and wanting to expand valuable time on something that would on the outside appear only to be done for the sake of being seen to be doing it." Participant 2 explained that the lack of interest is a result of a structured system that tolerates indifference and differentiation. Participant 2 described this system as,

> I've noticed that all of the departments are very much siloed by themselves, and nobody talks to anybody…I'm trying to break down some barriers there and, and show that there are options to do that crossover. I've worked with theater arts, through doing some design work with them, where students are building, props and stuff like that… You might not think that's career technology education, but any student who's going to be further on down the line, maybe going into a trade building with wood, creating stuff.

Participant 2 also offered this idea about changing the physical environment.

> If we were to look at the spaces where these activities are taking place, and we make them look more like the real world, then you'll find that students stop behaving like students and start behaving like young engineers, young designers, young scientists, because they are surrounded by an environment that is familiar to the environment that they'll be walking into once they leave (school).

They made this statement in summary: "blurring the boundary and making that pipeline clearer into the world of work rather than the world of further education."

Theme 5: Standardized Testing Is a Barrier to STEM Participation Expansion

Participants were asked about strategies that may help with removing barriers to expanding STEM learning experiences for students. Participant 5 stated, "remove some of the pressures of the SOL(*Standards of Learning)*… we should have more performance-based assessments, that would also be helpful." Participant 3, stated that "in this world of assessment, interdisciplinary education is the way that we motivate kids." Participant 1 stated "(when) students are outside of a VDOE mandated SOL testing requirement, we can put them in more real-world situations and do more project-based learning." Participant 2 spoke of reducing the academic load and SOL credits to allow more time to experience different careers. They said, "in order to give them time to experience the marketplace and go and actually to that job, …..they're not going to know what's available to them if we aren't showing them that." Participant 4 had some ideas about removing barriers to STEM integration, stating,

> We've been doing things like changing the application process, starting with younger students, getting rid of a test or two would be great. Then changing the perceptions of teachers that they don't have time to do these things, or that they don't use all of the parts of the lesson.

Reactions to the Leaky Pipeline Problem

Participants were all shown the graphic displaying the "Leaky Pipeline Problem." The discussion that ensued was one where each of the participants paused first and appeared to think about it deeply (see Figure 1).

Participant 1 said,

> Earlier on, we don't even give them the exposure. Um, the more opportunity we have the wider the pipeline is, and it doesn't narrow as quickly. Um, I would say more offerings. I mean it doesn't have to go from high school to college and drip into career. You can go right from high school into career. There's a Y valve there.

Participant 2 shared these thoughts on the leaky pipeline problem:

> It suggests a linear approach to education. And we know that, you know, our lives haven't been linear. I know there are some schools in the world that take a completely different approach to educating a child and what they should and shouldn't know at certain stages. And I think, that's what, what we do is squeeze it down. Those puddles are

> all those people who don't have the academic brains to get through the structure of the education system.

Participant 3 shared,

> I think that might be just what I've described to you that is happening in my school division. I like the visual that the pipe gets smaller because for me, the pipe represents opportunity. I think we have more opportunities right now in our younger grades than we do the older, and older and older, they get, we have more, um, we have more competing priorities.

Participant 4 offered the following:

> Well one of the big problems we have in elementary is the reduced amount of time for science instruction. Just because it's not tested. I hate to say that out loud. I think middle school is another leak for the state. We've tried to add engineering practice into the science standards of learning, but people don't really understand or do it. And I think we can do a better job at high school, really making sure kids know there are careers that they can do right out of high school, that are STEM careers. And um, not keep saying college is the only thing. I mean I could talk for two hours on this (graphic).

Finally, Participant 5 offered,

> I don't know if I would necessarily call it a problem. I think it's just the way as people grow, they begin to discover what they really like. Now, could we increase their desire for it? Maybe we could. But, I feel like we're beginning to do a really good job of getting them introduced to it early. Um, so maybe there will be less leaks as they go along.

Summary

This mixed-methods research study examined the local school division STEM policy and practice in Virginia to synthesize an effective STEM education strategy that warrants policy and funding supports. Using the 132 school divisions of the Virginia Department of Education, four research questions were explored.

In three steps, the researcher collected data. In the initial phase, it was determined whether phrases, words, and topics related to STEM education policy were present in the evaluation materials, which included websites, general sites, announcements, flyers, social media posts, course catalogs, budgets, and policy documents. The second stage consisted of a careful examination of the documents in order to identify themes important to the study questions. A count of districts STEM hits when searching their websites was recorded in a spreadsheet. A Yes/No for a STEM definition was recorded from the websites as well as if OST activities were announced on the website. Linking the discovered themes from both the website review and the participant interviews to the study questions and data analysis occurred during the third phase.

Content analysis revealed four themes: (a) existence of sense-making definition of STEM; (b) differentiated STEM programs; (c) scaling embedded STEM integration; (d) interest in STEM drives successful inclusion of gender, minority, and students with disabilities; and (e) standardized testing is a barrier to STEM integration. Theme 1 suggests that STEM education is viewed as either a single or multidisciplinary field, but there is no consensus on the nature of the material and pedagogical interactions between various STEM fields. Theme 2 explains that there are a variety of STEM experiences among educators, which may have been directed by school administrators with varying conceptions of STEM education and STEM integration. Theme 3 claims the graduating learning across academic grade bands where emphasis in middle and secondary education has shifted from content learning to content regurgitation. Greater focus has been placed on scientific knowledge application, the learning of technology manufacturing skills, and design thinking. Theme 4 suggests that while all participants stated that school administrators had rules and funds in place to promote full participation in STEM programs, they all concur that the success of the STEM curriculum, including its activities after school hours, is primarily based on the interests of the school's stakeholders. Theme 5 indicates that educators feel the pressure to focus on areas that are measured with standardized tests and struggle to find the time to incorporate things they feel are outside of the realm of assessment items. As students get older, there are more state testing requirements and less chances to explore STEM career options. These themes are further evaluated in the context of known STEM literature in the subsequent chapter.

Chapter 5: Discussion of Findings

Recent decades have seen a consistent growth in demand for STEM competencies in the workplace, with an increasing need for multidisciplinary skills in the job market. These demands are often presented as underserviced by the education system. STEM approaches to education seek to introduce a more holistic approach to education, promoting the integration of disciplines and highlighting the interconnected nature of the STEM subjects. This requires a move away from traditional methods of rote memorization and siloed disciplines towards a more generalized approach that highlights developing a variety of tools directed at problem solving. However, although this need is recognized in the literature, it is understudied and not well understood. Thus, through this mixed-methods study, the researcher sought to understand the implementation and effectiveness of STEM education through an examination of Virginia K-12 school divisions. The research was carried out through gathering publicly available documentation of K-12 STEM programming and statements made on school division websites. Next, interviews were conducted with local educators located at different school divisions within the state that had knowledge of the STEM programming. Both qualitative and quantitative data were collected to answer the following questions:

RQ1: Does the local school division have a definition of STEM education?

RQ2: If a school division has a definition of STEM education, does the definition employ the disciplinary definition or the integrated description of STEM education?

RQ3: Is there evidence in the school division that the STEM education activities are embedded in the school curriculum or part of the after school and extracurricular activities?

RQ4: Does the school division have a STEM for ALL approach or strategy to increase representation of gender, minorities, or students with disabilities in STEM?

Data analysis on the collected data yielded five themes: (a) existence of sense-making definition of STEM; (b) differentiated STEM Programs; (c) scaling embedded STEM integration; (d) interest in STEM drives successful inclusion of gender, minority, and students with disabilities; and (e) standardized testing is a barrier to STEM participation expansion. The chapter proceeds as follows. First, a discussion of the results by examination of each of the research questions, addressing the findings and situating the findings in the broader literature on STEM education. Second, the limitations of the study are discussed, followed by a section on the implications of the research for practitioners. Finally, implications for future research are discussed, followed by an overall conclusion.

Discussion of Results

Issues Related to Defining STEM

The first research question yielded insights into the role of sense-making in the definitions of STEM, which was the first theme from the data analyses. Quantitative data showed that only 17% of school divisions had a definition of STEM on their websites, and the qualitative data indicated from the interview participants that they demonstrated a lack of clarity in their own school divisions' definitions of STEM. When prompted to give definitions, some participants deferred to the school division or the VDOE website definition or acknowledged that the working definitions were imperfect, and communications were a "work in progress." As for personal definitions and interpretations of STEM, they demonstrated a clearer understanding, but their interpretations differed from one another. Whether a single, multidisciplinary field or an umbrella term for different fields, the participants demonstrated the unsettled nature of STEM definitions.

The unclear definitions of STEM from both the institutions and participants underscores a broader tension. The failure of many school divisions to first define STEM adequately, and subsequently to effectively communicate with educators, parents, and students, reflects conceptual confusion and leads to vague understandings of the concept. Researchers have identified contributing factors that exacerbate the institutional disconnect with regards to STEM programs (Carmichael, 2017; El-Deghaidy et al., 2017; Gardner, 2017; Honey et al., 2014).

The ongoing vagaries of STEM definition are not endogenous to Virginia school divisions. A lack of a standardized STEM definition remains central to ambiguous understandings, not just at the school, district, or division level, but as a general educational concept (English, 2016). There is considerable variation of whether STEM requires just one of the disciplines to be considered “STEM” or two or more (Franco & Patel, 2018). Without a centralized understanding, it is difficult to coordinate across schools to produce a standardized definition.

The issues also emerge from the participants themselves. Furthermore, state and national testing for educational benchmarks tend to silo disciplines into their traditional categories, rather than the combined framework of STEM. Teachers who have worked in a single discipline for extended periods may be uncomfortable with the changing definitions of STEM subjects and require additional training for updating pedagogical frameworks (El-Deghaidy et al., 2017; Park et al., 2017). Their lessons, habits of mind, and approaches to education have become engrained, and breaking these habits can be difficult (Fraser et al., 2018). This incentivizes schools, teachers, and students to teach and learn “to the test” and further calcifies the walls between subjects (Margot & Kettler, 2019; Martin-Paez et al., 2017). Without retraining and direction from school administrators, the confusion is likely to continue (Ames et al., 2017). Data analysis on both collected website and interview data demonstrated a lack of coordination between schools and teachers, as well as highly variable interpretations from STEM leadership. This conceptual confusion stems from a lack of broader definitions of STEM programs as well as resistance to changing the siloed nature of instruction in each individual discipline.

STEM as Disciplinary or Integrated

Given the unsettled definition of STEM, it is unsurprising that there is wide variance in the approach to integration, which led to the second theme: differentiated STEM programs. The interview participants discussed the difficulties of navigating multiple disciplines in a STEM program, a process so complicated that some participants expressed confusion as to the specifics. The process of integration often requires coordination between multiple teachers, who may or may not be trained in more than one STEM field, if any at all. Creating projects that have real-world application and adequately integrating multiple approaches that are appropriate to students' learning needs is a difficult task. Despite these difficulties, participants expressed strong support for the integration process and criticized the isolation of disciplines. One participant advocated the early separating of disciplines, with eventual integration over time.

The early separation of disciplines has been previously suggested by researchers such as Carmichael (2017), who created a four-step integration process that developed multidiscipline STEM approaches in stages. Carmichael advocated beginning with traditional disciplines, moving toward multi and interdisciplinary approaches as students mastered the basics of the subjects. The final stage was a transdisciplinary STEM approach that effectively combined all disciplines. Carmichael's proposal has been supported by other researchers, who have argued that total integration may not be optimal, as students must first understand and master the component skills before combining them in a classroom or project environment (McClure et al., 2017). Ultimately, STEM is greater than the sum of its constituent parts (Martin-Paez et al., 2019).

However, there are several factors that make the full integration of STEM subjects difficult. As mentioned above, teachers often lack the skills or the desire to give up on the traditional discipline approach to subjects. This resistance makes full buy-in from staff less than ideal. Math and the sciences, specifically chemistry and biology, have been traditionally separate from each other, with specialized teachers and tests, and thus may be even more difficult to integrate than technology and engineering (English, 2016). Furthermore, it is not always possible to fully integrate the disciplines. Some lessons, especially in biology, do not readily promote integration with math, physics, or engineering. There must be areas in which the disciplines may be studied individually, rather than being fully integrated (McClure et al., 2017). Additionally, each discipline has standardized assessments that are completed separately and, therefore, creates a barrier to full integration of the content.

The question of integrating engineering remains another central question. Engineering as a discipline is usually not introduced to curricula until later in the academic career and requires strong foundations in math and physics. When and how to integrate engineering beyond simply building “macaroni towers,” as one participant put it, is a central issue that must be addressed. Likewise, technology is underrepresented in integrated classes (Homlund et al., 2018). Technology may be bifurcated into two parts: technology to facilitate teaching of other subjects, such as mathematics programs, and technology as its own field, such as computer engineering. Researchers have advocated both utilizing technology in STEM as a standalone field with its own unique competencies as well as an integrated whole supporting the other STEM subjects (Homlund et al., 2018).

Ultimately, the large curricula decisions of integration are made at the school, division, regional, and state level, and teachers will have to adapt to the policy pronouncements of their defining institutions. Given the constant shifting of the political educational landscape and competing priorities of the policy makers, creating a long-term plan for STEM integration has not developed. The interaction of teachers and school division leaders should cultivate a culture of integration that seeks to combine and integrate multidisciplinary STEM programs when possible and allow for individual disciplines when necessary. The participants in this study both acknowledged the ongoing efforts at integration, recognized the inherent difficulties thereof, and advocated ongoing efforts. This has been especially difficult given the current focus on closing the gaps and learning loss after the interruption to learning during a pandemic. The website review revealed there is no standard method of communicating with stakeholders and no way to accurately summarize any integration efforts of STEM fields across the Commonwealth of Virginia. Indeed, the publicly available materials on the school division websites solidify the existence of primarily disciplined and siloed STEM activities. It would be great if there were more regional or even statewide communications about STEM activities and initiatives, activities, competitions, etc. or some other method for interested individuals to gather information.

Embedded vs. Out of School STEM Activities

The third research question yielded the third theme of scaling embedded STEM integration. All participants acknowledged the need for improved integration within STEM fields and discussed the ongoing process of that integration. This integration requires new pedagogical and lesson plan approaches, as technologies and approaches are integrated into a schoolwide curriculum. The website review did reveal many varying out of school STEM activities. There is no standard type of activity presented and OST activities are communicated in various ways across the school divisions. Currently, there is no collective way for the community to easily find or compare these OST activities. School divisions may publish information or links to the activities, but it did not appear that there was any way to collect data on who is participating in the OST activities or if it impacted their interest in embedded STEM activities. Further measures of interest and data collection of who is participating in both embedded and OST STEM is necessary.

The scaling process to embed more STEM requires step-by-step approaches that begin with fundamental skills and evolves over time into applied approaches and hands-on projects. This evolution of gaining basic knowledge and eventually applying it has been posited by several researchers. Carmichael (2017) laid out a four-step process that was previously discussed. Flores et al. (2017) recognized that approaches such as Carmichael's must be implemented over the entire educational life of the student, advocating a K-20 approach that takes a holistic strategic approach from early childhood education through higher education. The process must begin with the accumulation of basic knowledge in early education through noncompetitive trial and error lessons (Flores et al., 2019; Hurst et al., 2019). In middle school and beyond, students should be allowed more latitude in developing skills that will be useful in the job market through design and integrated approaches (Jang, 2010). These skills will be critical in the future, as the technological, design, engineering, and mathematics skills present in STEM bleed into non-STEM fields (Fayer et al., 2017). Indeed, students undergoing general elementary, middle, and high school education may find purpose for the skills developed even if they are not in a STEM field. Again, these updated educational approaches require new modes of teacher training, especially at early ages where educators are not necessarily prepared for the work of laying foundations of STEM approaches.

The participants all recognized the need for increasing levels of application as the students age and recognized that foundational skills must be taught at early ages before application begins. This approach to STEM education will require long-term reorientation of lessons to fundamentally prepare students for future competencies. These ties between STEM approaches and practical applications are a long-haul project and require a level of path dependency as students build their skills over time. Qualitative data suggested that even STEM leaders in the school division struggle to implement a vertically aligned STEM program to all students. Participants admitted that there are often waitlists or other courses that must be taken that compete for the same time in the student schedule. Additionally, the primary determinant of student participation both in and out of school time is student interest and desire to commit to the prescribed pathway. Noting that student interest is the primary factor of participation in STEM activities, the question of how school divisions are trying to foster interest and curiosity to increase STEM interest is an important consideration. Some school divisions certainly plan and execute STEM nights and fairs, but it is not known the impact these activities are having on participation in STEM coursework. A further discussion of the utility of this approach is present in the next section.

Strategies to Address Diversity in STEM

STEM has a representation problem. Numerous studies have revealed that the presence of significant divides in gender, race, ethnicity, and socioeconomic status (Briggs, 2017; Bullock, 2017; Chenyan et al., 2017; Hill et al., 2018; Xu, 2015; Yang et al., 2017). These discrepancies between groups depress educational and economic outcomes for graduates and engender inequalities upon society. When interrogated as to their perceptions of inequalities among students, participants overwhelmingly responded with the key variable of interest. Students enroll in STEM fields predominately due to personal interest in the subject matter, regardless of gender or demographic. Participants argued that the goal should not necessarily be to force students into STEM programs, but rather provide opportunity equity among students for the purposes of building interest. One participant observed that traditionally successful students – those with comparatively high-test scores or those enrolled in talented and gifted programs – were acclimated to a traditional school environment, with study, memorization, and testing as the foundation for learning. Those students who were less successful or skilled in these traditional metrics often are not accepted into competitive STEM programs and are thus denied the opportunity to study, even if they were interested. Thus, the participants advocated programs that eschewed traditional measurements of success but rather focused on active learning. Active learning beyond the scope of traditional classroom environments can give students the ability to build necessary work skills that are desirable in the marketplace and can yield outcomes that decrease inequalities.

Building interest in STEM subjects requires several components beyond the discarding of traditional classroom metrics. Researchers have highlighted the need to connect job market skills and real-world applications to classroom learning to demonstrate the utility of lessons (Tongu et al., 2017). Students who may not be motivated by grades could be interested in careers after their education, and this relevance outside of school is a contributing factor to maintaining interest.

Building interest also requires early introduction of concepts and the building of skills from an early age. Researchers have pointed out that students often develop antipathies towards subjects because of a perceived ineptitude (Crabtree et al., 2018). This early bias can stay with students longer after their first experiences. To contradict this effect, early, hands-on education in integrated STEM fields could foster lifelong relationships in a positive manner that encourages students to continue their education. To further underscore this point, Chenyan et al. (2017) highlighted some of the contributing factors that keep women out of STEM fields. The researchers identified the issue as a recruitment problem, not a talent problem. Women often feel ostracized by all-male environments and may have had negative (or no) early childhood experiences. Early acclimation to STEM fields can ameliorate these effects (Goris, 2020)

The participants in this study identified interest as the most salient variable in encouraging students to become and stay involved with STEM fields. This requires first introducing STEM subjects in a hands-on, interesting manner in the early stages of education to decrease bias among students. Furthermore, lessons that are not tied to traditional educational metrics, such as grading and testing, could encourage weaker students to continue their involvement. Many school divisions did announce events like STEM days, and Women in STEM events on their website. It is not known the extent to which participation in these has impacted other STEM programing participation. This is an excellent area for further study in Virginia. More concrete measures of who is participating in STEM and how that interest is developed is needed. It is also recommended that some consistent level of STEM be required and not simply relying on random acts of STEM to generate interest. Finally, ensuring that STEM courses have concrete career connections can encourage students to pursue goal-oriented education.

No direct conclusion can be made about those divisions with no definition of STEM because they could have one in an internal facing document that was not accessible. The focus rather is what do the school divisions have in common that did have more of a STEM focus on their website. One, it can be said that they likely have someone who is championing the initiative and organizing the communication. Two, they are primarily located in more densely populated areas and places where the local workforce also has a STEM focus. One can not assume that lack of mention via the website means lack of focus on the topic. It does generate questions regarding what can be done to improve the perception that episodic STEM is the norm and therefore accepted more broadly. This is an area that policy makers, school division leaders, and community stakeholders can coordinate on solutions and continue to press for further progress. Perhaps in places where the local economy is heavily impacted by STEM careers there is less of a randomness to the STEM activity in school because it is more engrained in the daily lives of students and their families.

Limitations

This research suffers from several limitations. First, quantitative and qualitative data were collected from publicly available documents, predominately from school division websites and used as a measurement of school divisions' commitment and understanding of STEM education. This measurement does not fully capture a school division's dedication, understanding of, or policy towards STEM. A school division could communicate with its constituent population through a variety of means, not necessarily just through a website. Furthermore, having a specific definition publicly available does not mean it does not have an internal definition.

Second, STEM policy in the U.S. education system is constantly changing, with new approaches to teaching and addressing student needs and goals. These changes often have long-term effects that are difficult to measure in the short term. A student entering kindergarten now will not graduate high school until well into the 2030s. Thus, this research represents a snapshot of Virginia's STEM landscape rather than providing longitudinal data for the future.

The researcher had an existing relationship with some of the school divisions through employment with a nonprofit STEM program, Project Lead The Way, that is active in Virginia. While great care was taken for that relationship not to influence any of the interactions, certainly the familiarity of supporting the STEM programs through their Project Lead The Way implementation could be a factor of how the participants responded to some of the questions during the interviews.

Finally, the COVID-19 pandemic and its lingering effects during the collection of data led to decreased response rates among potential interview participants. While the sample size was large enough to make some inferences about STEM programming in Virginia's school divisions, a larger sample could have provided a thicker layer of data as well as provided more variance in the sample. It is possible that more activities might have been announced on the websites if the review had not occurred during the pandemic. To check for this a mini review was done the summer of 2022 but found the websites were largely unchanged.

Implications for Practitioners

Each of the themes discussed has implications for practitioners, both teachers as well as school administrators. The first theme, the existence of sense making in STEM, suggests that schools and administrators should settle on clear definitions of STEM programs and ensure that these definitions are widely understood by the teachers, students, and public at large. The ambiguity surrounding what STEM is generates confusion about the ends and means of the program, especially among teachers. Also, once a clear definition of STEM is communicated, different activities and programming in STEM should be made available to all levels of educators in school divisions so that they can articulate and connect to a more vertically aligned

STEM program. Defining the purpose of the program can facilitate better goal setting among educators and a clearer communication of expectations to teachers.

The second theme involves the integration of multidisciplinary lessons into school curricula. This objective necessitates a closer investigation of the definitions and goals of STEM programs (as discussed in theme one) as well as providing teachers with the necessary resources and training to integrate lessons. Many teachers are not comfortable or do not have the prerequisite experience to teach integrated lessons, and thus must be supported by the school to adequately design curricula. It should be noted that these curricula need not be entirely integrated. Indeed, schools and teachers should be strategic about where they choose to integrate lessons into multidisciplinary STEM lessons and where they maintain discipline integrity, especially for younger learners.

The design should also keep in mind long-term goals (theme three). Integrated STEM lessons require a long-term plan that effectively creates foundational skills in early years and builds upon this foundation in subsequent grades. The long-term plan demands that students are armed with prerequisite competencies before being able to effectively utilize them in an integrated environment. Long-term planning requires longitudinal approaches to education in which teachers are adequately trained and understand their role in a path-dependent educational approach. Vertical articulation design for STEM could be another area of further research and development as well as how that can be communicated to the larger educational change agents.

Finally, the researcher recommends schools and teachers design lessons aimed at building interest in STEM fields, with special attention paid to minority demographics and women, who are underrepresented in STEM. Building and fostering interest requires three interrelated processes. First, early acclimation and understanding of STEM concepts reduces the likelihood of alienation among these students. Second, lessons should be designed outside the traditional framework of memorization and testing. Students from at-risk backgrounds often struggle in traditionally designed classrooms, and lessons that develop hands-on skills with real world application are more likely to foster interest. These lessons should be widely available and not predicated on previous academic achievement or performance on standardized testing. Finally, the lessons should have clear career implications beyond the educational sphere. Students who may be disinterested in grades or academic performance may be more inclined to explore and pursue STEM if it is likely to lead to gainful employment.

Implications for Future Research

This research prompts questions that have implications for future research. Given the lack of definition, difficulties of integration, long-term goals of STEM education, and the need for strategies to address lack of diversity in STEM, more research should be done as to the longitudinal effects of STEM education on academic performance, educational attainment, and economic outcomes of students. Children entering kindergarten now are likely to encounter a vastly different economic reality when they graduate in over a decade. The ongoing technological development of the economy is likely to produce new challenges and opportunities as the students enter the workforce. Educational effectiveness is not so much about the grades students attain in their academic career or how they perform on standardized tests, but how that academic career prepares them for the job market in the future. Young students entering the STEM pipeline at age six today will be introduced into a new system of integrated, multidisciplinary training as STEM programs expand in the coming years. The effectiveness of these programs is contingent on their outcomes. Further research is also needed on the effectiveness of STEM field integration. As different disciplines are combined for maximum effectiveness, research is needed on the most efficacious approaches to STEM education. Further discussion and best practices for increasing a diverse pipeline of STEM students is also warranted. Collecting examples for where school divisions have been successful in developing STEM interest and are graduating more students who are looking towards STEM careers should be shared across the different regions. Since the regional connections to STEM careers vary in Virginia it is also important that care is taken to explore many types of STEM fields and connect them to local school divisions. The ability to share, connect, and disseminate STEM successes across the regions is recommended as well as how this ties to the larger economy and workforce in Virginia. It seems there has been focus on this at the legislative level to create a STEM commission but what actions and accountability are in place to keep those efforts moving forward. The very question of whether the findings here are as random as they seem or is there something not yet known driving the work to integrate STEM offerings and expand them beyond traditional populations.

Conclusion

This mixed-methods study investigated the implementation of STEM programs in Virginia K-12 schools. Data were collected through two avenues: publicly available online resources from school divisions and interviews with STEM leaders in the Virginia educational system. Data analysis on these two sources yielded five themes: (a) existence of sense-making definition of STEM; (b) differentiated STEM programs; (c) scaling embedded STEM integration; (d) interest in STEM drives successful inclusion of gender, minority, and students with disabilities; and (e) standardized testing is a barrier to STEM participation. The researcher found that there is a lack of clear-cut definitions of STEM programs, and educators are confused about the educational standards and aims of such programs. STEM programs call for highly integrated lessons, incorporating a multidisciplinary approach to education. This poses significant challenges for administrators, teachers, and students, as they attempt the daunting task of integrating approaches in a practical, hands-on, and job-relevant way. A longitudinal approach to integration is therefore necessary to ensure early training lays the foundation for more interactive lessons later in students' academic career. There appears to be no consistency across school divisions in Virginia, thus leading to a random student STEM experience in Virginia. Finally, in order to better facilitate diversity in STEM fields, generating interest among students should be a primary goal, with extra weight placed on early introduction, nontraditional testing methods, and adequate connection to the job market. The workforce may be the most prominent instigator of further STEM educational development in Virginia. As those jobs continue to grow and are harder to fill with local talent, it is certain that fingers will be pointed at the local school division. Will it be at the economies' insistence that schools step up and demand more than these seemingly random pockets of excellence. Will the workforce gaps be what necessitates our movement from episodic STEM to clearly defined, vertically aligned, pipelines rich with greater diversity and far less leaks from untapped potential. It will also be important for further research and application of existing findings to press all stakeholders to continue to seek solutions and expand opportunities through policy initiatives.

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Appendix A: Interview Protocol

Interviews were conducted and recorded interviews using a video conferencing platform. Transcription was done, and the responses to interview questions were compared for trends. The participants were asked the following interview questions:

1. Tell me a little bit about yourself, your background, your role, and school district.
2. Does your school division have a definition of STEM?

   • "Yes" ---Where is it published, how is it communicated to staff and students?

   • If "No" definition for the district, how do you define STEM?
3. Can you describe some the STEM activities available at the elementary level?

   These can include both in and out of school time.
4. Can you describe some the STEM activities available at the middle school level?

   These can include both in and out of school time.
5. Can you describe some the STEM activities available at the high school level?

   These can include both in and out of school time experiences.
6. Traditionally, Science, Technology, Engineering, and Mathematics have been taught in isolated ways. Are there any efforts in your school division to create interdisciplinary experiences that incorporate 2 or more STEM fields?

   • Can you tell me more about them and if there is a desire to expand interdisciplinary options?
7. What type of career investigation, exploration, or work-based learning experiences exist for STEM fields?
8. Are any of the STEM activities limited to a specific group of students? Or open to all?
9. Can you describe how students are selected to participate?

• Is there an application-based process or does it require students to travel to different site locations?

10. Are there any efforts to increase diversity in the STEM career pipeline?

•Yes--- what are they?

•No--- why not?

11. Are there any barriers to prevent participation by some students?

- What barriers do you feel exist to expanding STEM learning experiences?

12. What strategies do you feel would help to remove the barriers you described?

13. When you look at the graphic (graphic displayed via presentation slide) of the leaky pipeline what do you think can be done to trouble shoot the leaks and increase the number of students who pursue careers in STEM?