THE SCHOOL DISTRICT OF PHILADELPHIA

STEM ACADEMIES WHITE PAPER

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Executive Summary

"Our Vision is for all children to have access to a great school, close to where they live."

- A high-quality STEM education requires a teaching and learning program that overlays interaction with STEM with a deep understanding of STEM related processes and artifacts. The Office of High School Support's Instructional Rigor Framework embodies this approach to STEM education (**FIGURE 1.1**).
- This approach to STEM education requires analytical (deductive) and synthetic (inductive) thinking skills (defined as "critical thinking" in this report) paired with catabolic (deconstruction) and anabolic (construction) application (defined as "hands-on learning" in this report).
- Curricular and instructional strength in secondary education (grades 6-12) is often the focus of state and national level STEM metrics; implementing a robust STEM program is predicated upon coordination of content knowledge and skills throughout K-12 (vertical alignment). (**FIGURE 1.2**).
- Equally, a robust STEM program that prepares students for postsecondary (college and career) readiness requires the diffusion of analytical and synthetic skills as well as catabolic and anabolic application throughout all core subject areas in each grade level (horizontal alignment).
- The STEM Academies Initiative utilizes the principles of vertical and horizontal alignment (defined as "21st-century learning" in this report) to promote coursework that aligns with the four stages of inquiry (confirmatory, structured, guided, and open –referred to as "problem-based learning"). (**FIGURE 1.3**).
- The STEM Academies Initiative begins with a Research and Design phase in which Central Office level partners come together for collaboration and coordination to determine resource allocation and procurement needs. Moreover, this phase requires solicitation from grant and community partners to support the STEM Academies Initiative's conceptual development and ultimate implementation.
- Implementation of the STEM Academies Initiative will occur in stages with the first two years (AY2020-21 and AY2021-22) designated as the pilot period. The selection of pilot schools is dependent on voluntary interest and participation of Assistant Superintendent(s); Principal(s); school leader(s); and, of course, teachers, parents, and students. (**FIGURE 1.4**).
- The STEM Academies Initiative will operate in an interactive external organizational environment that seeks to coordinate amongst stakeholders who support the program's mission of improving outcomes in student achievement and growth (PVAAS). (**FIGURE 1.5**).

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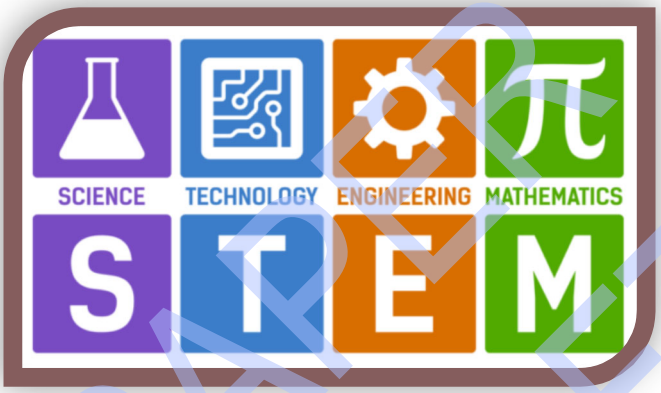
About the Deputy Chief of High School Supports

Mrs. Dean has more than 30 years of experience in education, having served at levels from classroom teacher to professional development facilitator to principal. Most recently, she was as the Principal of West Philadelphia HS where, she received the Lindback Award for Distinguished Principal Leadership, recognition as "Principal of the Year" by the Philadelphia Coaches Association, and conferred the Pillar of the Community Service Award from Saint John Lodge No. 44 (FAAM). Her leadership resulted in a grant investment of almost $75,000 into WPHS. Prior to her tenure there, she served as the Principal of Mastbaum Area Vocational-Technical School, which was the first Empowerment High School to make Adequate Yearly Progress for two consecutive years. Mrs. Dean holds a Master's Degree in Education, a principal's certification, a Directors' certification in Career and Technical Education, and a Superintendent's Letter of Eligibility.

About the Assistant Director of STEM

Dr. Ake-Little has a background in K-12 and higher education and most recently was a Research Assistant at Temple University, where he supported program evaluation of the University's core curriculum. Before higher education, he was as a biology teacher at the Charter High School for Architecture & Design and at The Agnes Irwin School. He has authored studies on teaching and learning, reviewed for academic journals, and published commentary *The Philadelphia Inquirer*, *Education Week* and *The Chronicle of Higher Education*, among others. In addition to a Principal PK-12 certificate, he holds certifications in General Science 7-12, Biology 7-12, Chemistry 7-12, and Physics 7-12. He earned his Ph.D. in Urban Education from Temple University, a M.Ed. in Secondary Science Education from Chestnut Hill College and a B.A. in History & Political Science from Drexel University.

HIGH-QUALITY STEM EDUCATION



Currently, STEM programming in the School District of Philadelphia (SDP) exists at various stages of development. At the Central Office level, various offices such as the Office of Curriculum, Instruction, and Assessment (OCIA), Office of Educational Technology (OET), and the Office of High School Supports (OHSS) each have implemented programming that identifies with one of the four components of STEM (Science, Technology, Engineering, and Mathematics). For instance, the Director of Gifted Education in the OCIA has taken the lead on developing a LEGO Education approach to engineering while the Senior Project Manager in the OET has taken the lead on computer science-related programming. Similarly, the Senior Project Manager in the OHSS manages the Advanced Placement program, which is increasingly becoming a crucial component in preparing students for STEM education at the post-secondary level.

This array of programming is, in turn, reflected at the building level where some schools have self-designated themselves as STEM schools in the absence of defined criteria as to what entails a robust STEM program. For example, the Chester A. Arthur School, a K-8 school that was designated an overall "Reinforce" school during AY2017-18, has a "STEM Center" despite PSSA Advanced/Proficient scores of 48/100 (ELA), 26/100 (Mathematics), and 21/100 (Science). Similarly, the Franklin Learning Center, a special admission high school, designates itself as a "STEM School" despite having an overall "Watch" designation and Keystone Advanced/Proficient scores of 59/100 (Literature), 16/100 (Algebra I), and 16/100 (Biology). However, the Julia R. Masterman Laboratory and Demonstration School, a magnet secondary school which does not explicitly identify itself as a "STEM School", boasts Keystone Advanced/Proficient (100/100: Literature, 99/100: Algebra I; 100/100: Biology) and average SAT scores (1361) that have consistently led to its ranking as a Top 10 school in Pennsylvania. Such variability in school-level academic quality suggests that there may be ambiguity about what qualifies as (a consistent level of) STEM programming.

DEFINING STEM EDUCATION

Several state and national authorities have sought to develop their measurement criterion of STEM education in the absence of a universal definition. For example, national ranking authorities such as *U.S. News & World Report* and *Newsweek* heavily rely on standardized test performance, particularly on national metrics such as SAT I/II & AP Exams to rank STEM programs. Other professional advisory bodies, such as the

National Council of Teachers in Mathematics and the National Science Teaching Association, evaluate STEM programs based on their adoption of national standards such as Common Core and NGSS, respectively. Similarly, via its redesign of the Advanced Placement Program, the College Board has developed its standards defining what constitutes high-quality STEM education. Finally, a widely held view depicts STEM education as intra and extra-curricular programming in which students are engaged in modern technologies such as robotics and 3D printing. Such divergent perspectives to STEM education can lead to confusion (and, by extension, friction) among stakeholders who operate on differing conceptual models of STEM education.

This report begins by developing a comprehensive and consistent definition of STEM education – a description that will guide the framework of this report. Researchers, too, have struggled to create a universal one-size-fits-all definition but have been successful in isolating certain elements that play a vital role in improving academic achievement as well as promoting interest in STEM education. (Peters-Burton et al., 2014; Erdogan & Stuessy, 2015; Morrison, Roth McDuffie & French, 2015) These studies all embody a common theme – STEM education is not exclusively a standalone discipline. They suggest that STEM program offerings require a robust curricular and instructional foundation from which more advanced coursework can organically develop. Thus, STEM education is *both* a rigorous approach to the fundamentals of science, technology, engineering, and mathematics *as well as* interdisciplinary coursework that seeks to integrate two or more of these components. However, in the absence of a strong foundation in its core subject elements, it is not surprising to see STEM programs manifest in multiple forms with predictably varied results. For instance, the Southwark School, a K-8 school, recently implemented the Full Option Science System (FOSS) approach to reinforce science teaching and learning resulting in a 24% increase on the Pennsylvania State Assessment System (PSSA) in one year after six (6) years of stagnant or declining performance. Other schools that advertise themselves as "STEM centered" may have a history of stagnant or declining mathematics and science outcomes that require a reformed approach to teaching and learning that is capable of preparing students for post-secondary opportunities.

THE STRATEGIC IMPORTANCE OF HIGH SCHOOLS

Whether intentional or otherwise, STEM programs are most strongly associated with the strength of high school rigor, with an accounting of mathematics and science coursework serving as a proxy measure for STEM rigor. However, such an approach often puts many urban high schools at a disadvantage given their lack of more advanced coursework, particularly in grades 11 and 12. For instance, Kelley & Sheppard (2008) found that nearly 50% of New York City (NYC) high schools did not offer physics, an essential subject for success in a variety of STEM fields. The authors concluded that one possibility was the inability of NYC schools to fill these positions due to prolonged vacancies and excessive turnover resulting from a shortage of physics teachers. Presumably, these schools also may have had difficulty in offering related courses such as engineering and even calculus. In many respects, high school student achievement reflects the totality of student learning during the primary (K-8)

years. Therefore, implementing a comprehensive STEM program in the late secondary grades (9-12) necessitates reinforcing curriculum and instruction throughout the primary (K-5) and early secondary (6-8) grades.

Beyond logistical-academic needs, high schools (and, more broadly, the secondary grades) are integral in the development of state and district accountability profiles. The SDP's internal measure of school quality – the School Performance Report (SPR) – evaluates high schools on four criteria: (1) achievement, (2) progress, (3) school climate, and (4) college and career outcomes. Achievement, as well as College and Career outcomes together, account for 40% of the SPR score with Academic Progress accounting for another 40%. In middle schools, which do not evaluate College and Career outcomes, Achievement and Academic Progress account for 40% and 30% of the SPR score, respectively. In either case, such a weighting suggests that, in the absence of a robust academic program, it is challenging for a school to advance from a lower ranking (e.g., "Intervene" and "Watch") to a higher one (e.g., "Reinforce" and "Model"). Currently, as of the 2018-19 SPR, 38/51 (62%) of the SDP's high schools are ranked as "Intervene" and "Watch" as are 10/19 (53%) of the middle schools – an indication that these middle and high schools require significant academic intervention.

Complimentarily, Pennsylvania's accountability measures designed under the state's Every Student Succeeds Act (ESSA) plan also evaluate schools on four criteria: (1) 2030 Goals & Targets, (2) Academic Growth Standard, (3) Performance Standards, and (4) Informational Outcomes. Academic Growth Standard speaks directly to performance on PSSA/Keystone measures in ELA/Literature, Math/Algebra I, and Science/Biology while Performance Standards will now include Industry-Based Learning and Rigorous Courses of Study – both of which are critical components of a robust STEM program. Perhaps the most ambitious of these measures is the 2030 Goals and Target expectations, which evaluate schools based on their progress (over a 13-year period) in reducing the number of individuals who are not proficient on PSSA/Keystone in half by 2030 (at which time the Elementary and Secondary Education Act law will again need to be reauthorized by the federal government). Schools that are struggling to meet those targets fall into one of two categories – CSI (Comprehensive Supports & Improvement) or TSI (Targeted Supports & Improvement) schools – based on their subgroup performance. As of 2018-19, 33/43 (77%) of the SDP's CSI designated schools, which must adhere to strict annual improvement plans compared to their TSI counterparts, are middle and high schools.

OFFICE OF HIGH SCHOOL SUPPORTS FOCUS: PROMOTING INSTRUCTIONAL RIGOR

A significant focus area of the OHSS under the leadership of the new Deputy Chief centers upon increasing instructional rigor at the secondary level. As noted in the previous section, STEM education necessitates the need for deliberate curricular and instructional planning at both the middle and high school years. Ideally, as students enter and progress through high school, they are not only able to excel in the foundational subjects,

which are perennially tested via state accountability exams, but also prepared to engage in the advanced coursework that is necessary for successful college and career success.

As will become the practice throughout this report, it is essential first to define some commonly used but often ambiguous terminology that has become almost ubiquitous in STEM education dialogue. The first of these terms is "**critical thinking**," which denotes some skill that goes beyond a rehearsal of knowledge. While "critical thinking" can vary by subject area and content matter, for this paper, it consists of the twin components of (1) **analytical** and (2) **synthetic thinking**. Analytical thinking is a function of *deductive reasoning*, in which a student must dissect an argument to see its component concepts. This approach is in contrast to synthetic thinking, which is a function of *inductive* reasoning, in which a student must take many ideas and integrate them to form one or more comprehensive arguments. (For the remainder of this report, the term "critical thinking" is discarded in favor of its component terms of analytical and synthetic thinking.) The second of these ambiguous terms is "**hands-on learning**" and, although the term is colloquially used to mean learning activities absent some passive content delivery, its users also employ variable definitions as to what constitutes this learning. For this report, the phrase "hands-on learning" is also parsed into its twin components of (1) **catabolic** and (2) **anabolic application**. The former term refers to a student's use of content knowledge to dissect phenomena into its constituent parts while the latter term refers to the application of knowledge to create novel processes and artifacts. It is important to note that these four skill sets do not operate alone. Analytical thinking and catabolic application depend on one another so that students can complement their thinking with practice and vice versa. Likewise, the same reasoning applies to synthetic thinking and anabolic application.

OFFICE OF HIGH SCHOOL SUPPORTS FOCUS: INSTRUCTIONAL RIGOR FRAMEWORK

FIGURE 1.1 outlines the proposed OHSS framework guiding the Office's approach to increasing instructional rigor in STEM education throughout the SDP's programs in grades 6-12. Each element of this framework contains the following features:

Strategy. Implementing a robust STEM program necessitates that the relevant math and science courses, particularly in the early secondary years (Grades 6-8), align with state and national standards (e.g., Common Core, Next Generation Science Standards). Although state standards already exist in tested subject areas, several professional associations have developed competency-based standards (e.g., IEEE Standards in Environmental Engineering) that can guide new course development. Parts II and III of this report detail both the pedagogical theory and proposed scope and sequence of coursework necessary to promote STEM college and career readiness.

Students. Student engagement in STEM manifests in two variants: (1) conceptual understanding and (2) practical application. Concerning the first variant, conceptual understanding is directly proportional to the

amount of scientific and mathematical content knowledge acquired by the student. Without this bedrock of content knowledge, the complex processes associated with technology and engineering provide an illusion of STEM learning with students able to *interact* with this phenomenon without *understanding* the processes that permit its operation. Unfortunately, the appearance of interaction leads to the false conclusion that students are engaged in STEM learning. Such a belief is analogous to saying that simply because one can drive (or *interacts*) with a car without an understanding of how engines and transmission work (based on the principles of thermodynamics and mechanical motion, respectively) that one is automatically an automotive engineer. Therefore, authentic STEM teaching and learning rests on students' ability to marry content knowledge with analytical and synthetic thinking.

The second variant of student engagement extends the first. Once students have developed fluency in math and science content knowledge, they can begin the tasks of anabolic and catabolic applications. Through catabolic practice, students can identify the causes and manifestations of potential problems they encounter in technology and engineering (e.g., a failed chemical reaction that renders a fire extinguisher useless or a faulty battery that prevents a phone from charging). Ultimately, the skills developed in catabolic application parlay into anabolic application where students can design original solutions to these problems (e.g., a new chemical approach that guarantees emission of a fire retardant or a longer-lasting mobile phone battery) as the basis for STEM innovation.

Teachers. Intensive professional development is crucial to the success of a robust STEM program. While teachers are indeed the content experts in their respective areas of certification, they may have gaps in some knowledge areas that are critical to student success in STEM. For instance, in a study produced by the National Association of Biology Teachers, only 46 percent of the 310 college instructors surveyed thought biotechnology was an essential topic for their course, and an even smaller 15 percent of respondents felt the same about bioinformatics. (Gregory, Ellis, and Orenstein, 2011) Since both content areas are necessary for success in a prominent STEM field – bioengineering – it stands to assume that many teachers likely have had minimal exposure to this content. Furthermore, even those who have proficiency in this content knowledge may not have had the opportunity to teach what is essentially an optional topic on state testing. Finally, given the limited resources of urban districts, developing a bioengineering course would require investment in classroom resources technologies associated with gel electrophoresis, blotting, and even polymerase chain reactions that warrant professional training before employing them for classroom use.

School Leaders. Principals and other building leaders, such as teacher coaches and learning specialists, are also essential to the viability of a substantive STEM program. In addition to the allocation of precious resources, building leaders play a role in facilitating the development of a budding STEM program. However, managing these resources, particularly time, money, and human energy, to developing (or reforming) a new program can be overwhelming, especially for principals who are frequently engaged in addressing school climate issues. For example, attempting to schedule some collaborative time amongst teachers and building leaders often requires

principals to make (undesirable) adjustments such as hiring new staff or increasing class size altogether. A report presented at the SDP's 2019 Research, Policy, and Practice conference, indicated that teachers' beliefs' about their principals' consist implementation of district-provided professional development was not only highly variable but also had an overall minimal effect on increasing math and science outcomes. (Ake-Little, 2019)

Central Office. Lastly, Central Office serves as the orchestrating agent and support system necessary to ensure not only that short-term needs receive their due attention (e.g., data analysis reports, professional development seminars) but also ensure the long-term viability of a STEM initiative (e.g., procuring funds to support schools and expand the program, developing internal measures of quality). Ultimately, the success of a comprehensive STEM program is highly dependent on a reciprocal relationship between the Central Office, school leaders, and classroom teachers. A focus on improving outcomes in student achievement and growth (PVAAS) is proportional to the strength of that relationship, particularly concerning implementation and feedback.

THE STEM ACADEMIES INITIATIVE

As discussed extensively thus far, the success of a robust STEM program that (1) engages students, (2) prepares them for postsecondary readiness, and (3) demonstrates efficacy via improvements in student achievement and growth (PVAAS), is grounded in rigorous preparatory coursework. While the term "interdisciplinary learning" is somewhat conceptually easy to grasp, its practice has proved to be far more elusive. This difficulty maybe not only the product of school structure but also the preparation and expectation of teachers. To the first point, the very nature of departmental programming at the secondary level encourages "siloing" (i.e., distinct separation) whereas, to the second point, arguably the more significant obstacle is the expectation that once given the command, teachers will intuitively know how to teach interdisciplinary without any guidance to the practice. (Teachers hold a certificate that designates them as content experts in their subject areas.)

The remainder of this report outlines a new and structured approach to STEM education in the School District of Philadelphia (SDP) that seeks to address many of the curricular, instructional, and logistical issues outlined above in the form of the **STEM Academies Initiative,** with each STEM Academy serving as an interdisciplinary program in grades 6-12. In the early secondary years (6-8), students develop a strong foundation in content knowledge supplemented with analytical thinking skills and catabolic application practice. In the late secondary years (9-12), students continue their acquisition of content knowledge, but in these years, synthetic thinking and anabolic application complement early secondary skills. The next section of this White Paper discusses the curricular and instructional approach of the STEM Academies Initiative to justify its implementation in the second half of this report.

THE STEM ACADEMIES INITIATIVE
[PART I: THE CURRICULAR & INSTRUCTIONAL APPROACH]

As discussed extensively in the preceding pages, developing an effective STEM program necessitates a solid curricular and instructional foundation, especially in science, mathematics, and language arts, at every grade level so that students can engage conceptually and practically in rigorous technology and engineering education. **Thus, the strength of a STEM program is directly proportional to the power of its core curriculum and instruction.** For instance, research has shown that the strongest predictor of success in computer coding is not the knowledge of the computer language itself, but rather the ability to master concepts of written grammar and organization. (Vee, 2013; Mannila et al., 2014) In a sense, this is intuitive; computer programming requires meticulous attention to syntax with even a slight error causing a host of code execution errors. Likewise, the troubleshooting process (debugging) requires the programmer to review how one block of code may influence the functioning of a subsequent block. In the same vein, research has found that there is a strong relationship between vocabulary development and conceptual understanding in mathematics. (DiGisi & Flemingg, 2005; Valle et al., 2013) Closely related terminology such as *supplementary* and *complementary* (angles) requires students to decode (analytical thinking) these terms before successfully applying them. Perhaps the most salient example of the relationship between reading, mathematics, and science are word problems, which require students not only to decode text to garner relevant information (analytical thinking) but also relate this information to reach a solution (synthetic thinking).

SCAFFOLDING SKILLS TO PROMOTE STUDENT ACHIEVEMENT IN STEM

FIGURE 1.2 provides a schematic that illustrates the importance of content and skill progression throughout a student's primary and secondary years such that secondary graduates are college and career ready to pursue opportunities in a host of STEM-related fields. The top half of the schema challenges the traditional perception that intensive STEM education is exclusive to students interested in engaging these subjects in higher education. While institutions of higher education (IHEs) undoubtedly have well-developed undergraduate and graduate-level STEM programs that prepare their students for some of the most academically intensive STEM careers (e.g., medical research, chemical, and petroleum engineering), only recently have career and technical

education garnered a significant level of attention as an alternative STEM pathway. Although technical education has a historical perception of being an alternative to undergraduate studies, these pathways do offer students who may not otherwise plan to attend traditional four-year postsecondary degree programs the possibility to develop valuable STEM-related content knowledge and skill development. Consequently, this schema attempts to identify the skillsets needed for STEM success in both routes with the focus of improving student achievement and growth (PVAAS) in either as the ultimate goal of the STEM Academies Initiative.

The middle portion of Figure 1.2 illustrates how these skills develop in the context of interdisciplinary teaching and learning. Note that content knowledge is the foundation upon which these skillsets and applications flourish throughout all grade levels. Logic dictates that a robust body of content knowledge allows students to dissect and relate one or more ideas and, hence, the more developed this foundation of content knowledge, the higher the potential for students to develop their faculties in catabolic and anabolic application. However, as the diagram indicates, a synthetic mindset capable of anabolic application is heavily dependent on mastering both content knowledge as well as analytical thinking and catabolic application. The most recent neurological research argues that the development of intelligence correlates not with the number of *direct* (1:1) neural connections (as previously thought) but with the number of *interrelated* (1: multiple) pathways. (Benedek, Jung, and Vartanian, 2018; Genç et al., 2018) Thus, a direct connection would facilitate analytical thought (parsing a concept to create links between component ideas) while an interrelated connection would be more conducive to synthetic thinking (connecting ideas housed in multiple neurons to develop a new concept). However, a neuron cannot develop multiple interrelated connections (synthetic thinking) without first forming direct relationships (analytical thinking). (Ramchandran, Zeien, and Andreasen, 2019)

The bottom third of Figure 1.2 correlates the progression of content knowledge, analytical thinking, and catabolic application as well as synthetic thinking and anabolic application with the four (4) stages of inquiry, or more broadly termed "**problem-based learning**" (PBL). Like its counterparts, "critical thinking" and "hands-on learning," the term "problem-based learning" has a highly variable definition depending on the audience. However, for discussion throughout this report, it is essential to dissect this broad term into its components. Banchi & Bell (2008) as well as Owens, Hester, and Teale (2002) discuss the four stages of PBL are as follows:

(1) **Confirmatory Inquiry** – In this stage, the instructor poses the question, the procedure is explicitly stated, and the meaning/significance of the solution provided. This type of inquiry is the most restrictive and most teacher-centered.

(2) **Structured Inquiry** – In this stage, the instructor poses the question, and the procedure stated explicitly; however, the solution is left open to students to interpret based on their observations.

(3) **Guided Inquiry** – In this stage, the instructor only poses the question, but students must develop the procedure given the resources provided and interpret the solution based on their observations.

(4) **Open Inquiry** – In this stage, all three elements of experimental design – question, procedure, and solution – are left for the student to create. This stage is the most advanced level of inquiry and mirrors the professional research process.

As these definitions suggest, the stages of inquiry are sequential rather than concurrent (e.g., it is not possible to engage in guided inquiry without having first mastered confirmatory and structured inquiry). Confirmatory and structured inquiries are most associated with analytical thinking and catabolic application since they are instructor directed processes. Conversely, guided and open inquiries are most closely related to synthetic thinking and catabolic application as they are student-directed processes.

Finally, note in Figure 1.2 that the progression of skill, application, and inquiry all work in the services of improving outcomes student achievement and growth (PVAAS). In contrast to the No Child Left Behind (NCLB) Act of 2001, Pennsylvania's ESSA requirement requires schools to show evidence of student progress with incremental benchmarks catered to the character of each school (as opposed to NCLB's universal standard, which measured all schools with the context of its character). Ideally, the goal of this pedagogical approach is for all students to master synthetic thinking and anabolic application. However, what is perhaps more important than such an all-encompassing standard is the need to increase *individual* student growth as evidenced by the Pennsylvania Value-Added Assessment System (PVAAS). Theoretically, as students; improve their skills and application abilities via successive stages in the inquiry process, they will progress to the highest stages of thinking and application per their own intellectual and experiential development.

THE SIGNIFICANCE OF HORIZONTAL & VERTICAL ALIGNMENT

The schematic also suggests the importance of interdisciplinary learning, given the overlap in skills. Advocates of STEM education often refer to the term "**21st-century learning**", which too can assume amorphous definitions based on the user and context. For instance, an accountant might define the term to include skills such as financial literacy as well as some understanding of the principles of business and economics. However, a neurosurgeon would define the term to include the ability to process a large volume of information in a short period, especially if the patient is in the operating theater. Presumably "21st-century learning" here would refer to skills such as data analysis (of patient metrics) and the operation of highly specialized surgical technologies.

So for this report," 21st-century learning" is defined as (1) **vertical** and (2) **horizontal** alignment. Vertical alignment is the arrangement of coursework curriculum, scope, and sequence in such a way that by the time students enroll in grade 11 and 12 STEM courses, they have been exposed to the concepts needed to develop proficiency in that course in grades K-10. Conversely, horizontal alignment is the interrelatedness of ideas within a grade level (i.e., interdisciplinary teaching and learning) such that each course simultaneously draws upon and complements the skills and content from its peer courses. Even for students who may not wish to

pursue a STEM career, the push for horizontal and vertical alignment will serve them in virtually every post-secondary option that requires analytical or synthetic thinking skills.

Note that horizontal and vertical alignments are not only essential to the development of a successful STEM education program but have far-reaching consequences for postsecondary (college and career readiness). Concerning K-12 teaching and learning, some researchers have expressed concerns about what they perceive to be a mismatch between state standards, which articulate the fundamentals of postsecondary readiness, and school curricula aimed at preparing students for college and career pathways. (Conley, 2007; Barnes & Slate, 2013) These concerns appear to have been validated by a recent report issued by The New Teacher Project (2018) titled *The Opportunity Myth*, in which researchers studied five school environments (district, charter, urban, and rural). The authors note three important findings regarding the disassociation between the curriculum and standards: (1) 71 percent of students succeeded on assignments given, but only 17 percent of those assignments were actually on grade level, (2) free and reduced lunch students and students of color consistently engaged in lower-level assignments coupled with weaker teaching, and (3) some classrooms serving predominantly students of color offered not a single assignment that was on grade level when, in reality, those students did only slightly less well on the harder, grade-level assignments than their peers when offered the opportunity.

By extension, the absence of horizontal and vertical alignment can serve as significant obstacles to postsecondary success even if students gain admission or employment in colleges or career pathways, respectively. For instance, a diluted secondary curriculum can be highly problematic for student retention in postsecondary education. Institutions of higher education by and large do not count the remedial coursework needed to begin a degree program towards degree credit completion. Erstwhile, the "tuition meter" is running for these students engaged in remedial coursework – grade-level content that was otherwise left unmastered at the secondary level. Thus, it should come as no surprise that aggravated tuition costs coupled with an extended timeline for graduation make for a surefire recipe for low student retention. (Stewart, Lim, & Kim, 2015).

THE PIVOTAL ROLE OF TEACHER PROFESSIONAL DEVELOPMENT

Implementing a rigorous curriculum and instruction program in the form of the STEM Academies Initiative requires the support and expertise of a content-rich and highly skilled teaching staff. Because of their content knowledge and pedagogical experience, several studies have argued that teachers are at the core element of improving student achievement. (Sanders, Wright, & Horn, 1997; Rockoff, 2004; Stronge, Ward, & Grant, 2011) However, meaningful professional development can be difficult, considering the many time-consuming stressors teachers face in the classroom. Especially in urban settings, teachers are increasingly asked to do more with fewer resources. It is no surprise then that Guskey (2002) has argued that many teachers cite in-school professional development (e.g., staff meetings, in-service days) as either too theoretical, without clear purpose and application, or altogether poorly executed, with some going noting that professional development detracts from high prized curricular and instructional planning time.

However, professional development can be a valuable tool if appropriately implemented. Desimone (2009) has articulated the core features of active professional development, including: (1) content focus, (2) active professional learning opportunities, (3) sufficient duration of learning opportunities, (4) coherence (the degree to which learning opportunities are consistent with teacher beliefs), (5) knowledge about the practice and relationship with student outcome, and (6) collective participation. By extension, Leone and Drakeford (1999) note that the most successful staff professional development programs seek teacher input, provide chances to work with colleagues, and include opportunities to visit and observe teaching in other settings – in short, a "bottom-up" organic approach to professional development rather than the traditional "top-down" approach so common in many school environments.

In terms of interdisciplinary content-related professional development, Heller & Greenleaf (2007) note that content area teachers rarely provide explicit and systematic instruction of reading and writing skills because they do not think of themselves as ELA teachers. Thus, they recommend using teacher professional development as a working collaboration between various subject matter teachers to develop ways these skeptical content level teachers can teach content-specific vocabulary and the associated reading comprehension skills needed to master fundamental concepts in their respective areas. Additionally, ELA teachers can support their content area colleagues by assisting in the design of content specific textual analysis lessons. Gersten et al. (2001) argue that students fail to recognize that textual organization is not the same across all content-areas. For instance, science texts (and much of science instruction) often use a procedural approach, showing, for example, how steps in a process depend on one another. The same is valid for mathematics texts and instruction, which embody analytical (deductive) reasoning, meticulous step-by-step procedure, and logic. Conversely, history texts may be presented chronologically, often without explicit attention to the interrelatedness of events. Thus, encouraging content area teachers to integrate textual analysis into their courses allows students to connect content, theories, and processes rather than commit to rote memorization of facts.

With regards to instructional practices, even incorporating (or refreshing) best practices and approaches encountered in pre-service teacher education can help teachers rejuvenate their practice. Maccini and Gagnon (2006) found that among mathematics teachers, the number of methods courses taken by these teachers coupled with their mastery of content knowledge aided in their instructional flexibility, leading to an increased number of instructional practices and accommodations used for diverse learners. Another effective professional development practice is mentoring and coaching. When mentoring and coaching content-specific in a professional learning context, mentors and mentees come together and engage in an active exchange of knowledge and experiences regarding instructional strategies. Participating teachers are then able to observe later, comment, question, and reflect on their practices. The entire exercise can become a learning process for both parties to the ultimate benefit for their students. (Smith & Ingersoll, 2004) New technologies, such as videoconferencing, e-coaching, and online social networking all have the potential to enhance this practice by tapping into an expansive network of highly competent educators.

PRINCIPAL LEADERSHIP AND SUPPORTING STEM TEACHERS

Lastly, administrators also play a critical role in managing school climate, allocating resources, and aiding in teacher professional development. For instance, principals can support their STEM programs by surveying and soliciting suggestions for the types of professional development (content-based, instructional, or postsecondary pathways related) that are of critical need in their schools. Working with teachers to provide them with autonomy over the direction of their professional development is strongly associated with an increased probability that teachers will not only implement their learning with fidelity but also likely seek independent training in a given area. (Wei, Darling-Hammond, and Adamson, 2010)

Furthermore, as instructional leaders, principals should consider developing a working knowledge of the STEM subjects taught in their school. Lochmiller (2016) noted in his analysis of teacher evaluations, the feedback provided by principals to mathematics and science teachers focused on pedagogy as opposed to content understanding, leading many of these teachers to view the input as immaterial. Moreover, he observed that this feedback derived from the administrator's own teaching experience and, therefore, they approached mathematics and science education with the same instructional lens as they did with their non-STEM peers. Given the importance of teacher evaluations, particularly in improving classroom teaching and learning, principals likely desire to offer the highest possible quality feedback to ensure increases in student achievement and outcomes (PVAAS).

THE STEM ACADEMIES INITIATIVE
[PART II: STRATEGIC IMPLEMENTATION]

Thus far, this report has articulated a theoretical justification and approach to the STEM Academies Initiative. The remainder of this report, however, pivots towards the implementation of this program with a discussion of the human and financial resources necessary to translate the STEM Academies Initiative from concept to praxis. As noted in the beginning pages of this report, the STEM Academies Initiative seeks to (1) use postsecondary (college and career readiness) preparedness to develop a retrospective academic framework that seeks to address potential gaps in the extant curricula; (2) implement a program-wide interdisciplinary approach in said framework such that there is alliance both in terms of content knowledge and progression of skill development (analytical and synthetic), application (catabolic and anabolic), as well as inquiry (from confirmatory to open); (3), use a teacher-centered approach to professional development (e.g., the self-selection of topics that focus on depth over breadth); and (4) combine elements of both collaboration and coordination with stakeholders to achieve a sustainable approach to STEM education. Thus, the promise of the STEM Academies Initiative lies in its potential to serve as a pedagogical laboratory that, via the trials and tribulations of its strategic implementation, can provide empirical support and feedback for each successive phase of scale.

RATIONALE & FRAMEWORK FOR PROPOSED STEM ACADEMIES INITIATIVE CURRICULAR AND INSTRUCTIONAL PROGRAMMING

As discussed in the preceding section, without horizontal and vertical alignment, it is challenging to develop a successful STEM program that shows improvements in student achievement and growth (PVAAS). Of foundational importance are well-developed reading and writing skills, especially in the area of non-fiction and technical language arts. Non-fiction, as well as technical reading and writing, are ideally introduced in the early secondary (6-8), and late secondary (9-12) years, respectively, since secondary education often requires students to move from confirmatory inquiry to structured and guided modes of problem-based learning. (English & Mousoulides, 2009; Gardner, 2011) Moreover, non-fiction and technical reading and writing also offer students the opportunity to engage in analytical and synthetics thinking, respectively, since the former focuses on

students' ability to analyze and deconstruct text into its component arguments while the latter focuses on students' skills to synthesize and construct new arguments. This reasoning does not discount the role of fictional reading; in fact, it is usually the venue by which students, particularly in the primary years, are introduced to the fundamental of reading comprehension (e.g., tone of the author, main idea/theme of selection, vocabulary development). However, fictional reading does not necessarily depend on background contextual knowledge, as is mostly the case with non-fiction reading. Readers of fiction are invited (and even required) to immerse themselves in the author's world, whereas readers of non-fiction must connect an authentic knowledge of content, processes, and lived experiences to the author's arguments. Even fiction in the high school years assumes many of these elements since students are called to integrate fictional text with its historical, social, and economic context in pursuit of literary critique (e.g., Beloved, The Great Gatsby, and Great Expectations).

Likewise, abstract mathematical thinking in the form of manipulating numbers (e.g., fractions to ratios, long-form division), as well as analytical reasoning (e.g., explaining proofs, logic games), are also skills vital to STEM success although here too students have pronounced difficulty as evidenced by national Common Core outcomes. (Phillips & Wong, 2010; Schmidt & Houang, 2012) As mentioned above, word problems are indicative of the fusion of these competencies. For instance, the classic word problem, introduced in either Pre-Algebra or Algebra I, where students are required to calculate the meeting times of two trains departing from stations in two distant states only illustrates the need for students to use non-fiction related skills such as technical (mathematical) and spatial reasoning (vis-à-vis geography) to arrive at the correct solution.

As students progress beyond the middle years, they begin to acquire both content knowledge in science, technology, and engineering that are parallel to their analytical and synthetic skill development in reading, writing, and mathematics. Ultimately, by the late secondary (9-12) years, students begin to engage in the type of authentic STEM learning characterized by catabolic and anabolic applications so frequently associated with the widely held view of STEM education. So, then it stands to reason that gaps in curriculum and instruction in the early years will inevitably lead to a foundation that needs reinforcement in later years. Several researchers have noted that in many urban schools, even the most senior level courses offered in grades 11 and 12 can quickly become enveloped in remedial as opposed to grade-level coursework. (Hoyt & Sorensen, 2001; Schiller & Hunt, 2011; Tierney & Garcia, 2008).

FIGURE 1.3 tracks the progression of skill and inquiry in addition to the curricular and instructional scope and sequence necessary to achieve the STEM-related student achievement and growth (PVAAS) not only on state standardized testing (i.e., PSSA/Keystone Exams) but also national exams (e.g., SAT I/II, ACT, AP, IB). Thus, there is a mutualistic relationship between coursework and pedagogy in which one reinforces the other both via horizontal and vertical alignment. For instance, the Computer Science Discoveries course sequence, proposed during the early secondary (6-8) years, requires students to concurrently engage in mathematics coursework that emphasizes the elements of rudimentary reasoning (e.g., abstract thinking and logic) embodied in courses such as pre-algebra. Likewise, an emphasis on non-fiction reading and writing necessitates content

knowledge development in science and social studies such that students can effectively dissect text that attempts to explain a process (e.g., scientific, political, socioeconomic). In the late secondary years (9-12), the type of intensive STEM coursework most often associated with deep STEM engagement (and highly valued by IHEs and employers, is not possible without a solid foundation in core subjects in grades K-8. For instance, the AP Seminar course requires students to actively participate in discussions grounded in technical readings whereas AP Research course extends student academic development such that they are responsible for their open inquiry project (not exclusive to STEM). In essence, success in that two-course sequence depends on students' proficiency in non-fiction and technical reading and writing; a deep reservoir of content knowledge garnered in history as well as the natural/social sciences, and abstract reasoning/logic skills developed in mathematics. Finally, the proposed sequence also accommodates students who wish to pursue post-secondary options in either higher education or the workforce.

PHASES OF STEM ACADEMIES INITIATIVE IMPLEMENTATION

Given the ambitious nature of the STEM Academies Initiative, especially within the context of one of the largest school districts in the country, a district-wide implementation plan necessitates the need for a piloting period complete with recursive feedback and evaluation phases. **FIGURE 1.4** depicts an implementation timeline for the first three years of STEM Academies Initiative with Year 1 (Research & Design Phase), Year 2 (Micro-Level β Implementation in select schools), and Year 3 (Meso-Level γ Implementation in a particular community or Learning Network). Note that Years 4+ (Macro-Level Gold Implementation throughout the SDP) do not appear in this timeline because (1) this scale of implementation is highly dependent on the progress of the preceding years and (2) the variable nature of time as a function of financial and political forces make it difficult to forecast such a broad application.

Year 1: Research & Design Phase. The overarching focus of Year 1 (AY2019-20) is to use this framework as a blueprint to guide a seamless translation of the STEM Academies Initiative from concept to praxis, particularly for the Micro-Level β Implementation period. As this is an altogether new undertaking by the SDP, the initial months of this year are devoted to research, logistical design, and the refinement of the program with the intent of starting the piloting period in AY2020-21. However, to ensure a high level of success, efficient use of resources, and a desirable implementation, this design phase will require a series of successive steps (as outlined in Figure 1.4) that begins with identifying collaborative partners both within and outside the SDP as well as potential pilot candidates. Coordination and collaboration at the Central Office level require (1) taking account stock of and marshaling internal resources, (2) designing *STEM Academies centered* professional development, and (3) partnering with outside organizations for the acquisition of financial, technical, and instructional support. Additionally, the selection of potential pilot schools is predicated on meeting a series of criterion including but not limited to (1) school climate stability, (2) history of academic performance (to best match curricular and instructional programming options, (3) and the "feeder patterns" of school enrollment so that longitudinal

evaluations over the life of the STEM Academies Initiative are possible. Perhaps most important is voluntary engagement since research has shown that educators who seek to voluntarily implement a pedagogical approach, as opposed to one dictated to them by fiat, are much more likely not only to sustain its implementation in the long-term but also find ways to actively incorporate and further develop the approach in the form of capacity building. (Fullan, 2005; Harris, 2001)

Year 2: Micro-level β Implementation. This phase shifts focus away from Central Office level conceptual design towards building level execution. Critical to the success of the pilot phase is frequent and recursive consultations with building-level leaders – ranging from Assistant Superintendent(s) to Principal(s) and, perhaps most importantly, to the teachers and students – all of whom are ultimately responsible for the quality of teaching and learning as measured by outcomes in student achievement and growth (PVAAS). Moreover, their feedback is critical to refining the STEM Academies Initiative model, primarily to address curricular and instructional gaps between *where students are* and *where students should* be. As the focus shifts towards building level implementation, STEM Academies collaborators at the Central Office level will need to assume an auxiliary role that supports building-level leaders in (1) troubleshooting logistical issues such as classroom support and resource acquisition, (2) professional development that is designed to promote depth over breadth (i.e., teacher-selected topics that focus on addressing obstacles to enhancing classroom teaching and learning), and (3) monitoring student- and program-level progress. Here, the Initiative's collaborative approach will likely expand to the Office of Teaching and Learning as well as the Office of Evaluation, Research, and Accountability.

Year 3: Meso-level γ Implementation. This phase centers upon expanding the pilot to a medium scale such as a Learning Network. Crucial to the success of this stage is the feedback and evaluation garnered at the β phase, which will be used to inform not only *where* and *when* the STEM Academies Initiatives might be most effectively applied, but also *what* possible challenges appear as the consequence of scaling and *how* to address them in anticipation of more significant scaling. For instance, some issues such as the need for more instructional resources might be associated with a linear need (i.e., the amount needed is proportional to the scale of the operation) whereas other concerns such as professional development might be an exponential need (i.e., the amount required increases disproportionately and substantially over the scaling period). In either case, γ implementation requires a delicate balance between Central Office level coordination and Building level management. Integrating the STEM Academies Initiative across an entire network will invariably require collaboration with the Chief Schools Office to provide support over a broader range of administrators, faculty, and students. It is ultimately the success of this phase that will determine the possibility of both the likelihood and extent of a district-wide implementation to ensure that the program becomes embedded into the SDP milieu.

INTEGRATING CAREER & TECHNICAL EDUCATION INTO THE STEM ACADEMIES INITIATIVE

CTE has historically been an alternative academic path for students who may not wish to pursue a traditional post-secondary education – let alone a four-year degree in formal mathematics or science course of study. However, CTE and STEM education are a complementary fit since technical fields ranging from the construction trades to agriculture to automotive mechanics require a strong foundation in and nuanced comprehensive of STEM principles. For instance, an electrician would likely need to have a solid conceptual understanding of concepts such as current, voltage, resistance, and (parallel or series) circuits performing wiring-related tasks. Likewise, someone engaged in animal husbandry would need to understand the principles of genetics, ecosystems, and even physiology in order to manage livestock.

The 11th and 12th grades often serve as preparation for post-secondary education, incorporating advanced coursework that seeks to mirror the rigor and expectations associated with college academic life. However, CTE programming is not generally associated with college readiness and, therefore, has operated mostly as an independent academic track. However, as noted above, CTE programming can be a reliable curricular and instructional partner in preparing students for STEM-related careers in any post-secondary option. Moreover, this complementary approach is neither new nor radical. The New York City Department of Education (NYCDoE) operates multiple schools throughout its five-borough jurisdiction built on this *modus operandi* with the Staten Island Technical High School and the Brooklyn Technical High School ranking seventh and 10th both in the NYCDoE *and* the State of New York. (U.S. News & World Report, 2019) Here, the SDP already has a comprehensive CTE program, that is housed in the OHSS and dispersed amongst some of the district's various special admission high schools. Indeed, individual CTE high schools such as Jules E. Mastbaum Vocational-Technical School and the Swenson Arts & Tech High School each already have well-developed CTE programs with options for students to pursue a range of CTE careers and concomitant certifications. Although not all high schools in the SDP have such an extensive CTE program catalog, offering a unified curricular approach that connects STEM Academies programming in grades 6-9 with CTE programming in grades 10-12 could provide many more students, who would at present not qualify for admission into pre-existing CTE programs, with the opportunity for CTE or college preparatory preparation in high school. Moreover, the SDP's CTE programs currently operate at 93.3% capacity; since the program's goal is for 100% enrollment, a unified SDP-CTE program could potentially provide a robust pipeline for CTE admission.

Given its fundamental purpose to prepare students for post-secondary options, the SDP's CTE program has sought to align its coursework with those offered at colleges and universities, trades schools, and apprenticeships with the intent of earning college credits within CTE programs. Although the SDP's CTE programs do engage in horizontal and vertical alignment with postsecondary institutions, there may exist a possible gap in grades 6-9 particularly in terms of content knowledge and skills, which are critical to student

achievement and success in the battery of CTE programs offered in grades 10-12. For instance, the SDP's CTE graduates have boasted an average of 60% advanced/competent on standardized testing provided by the National Occupational Competency Testing Institute (NOCTI), whose tests align with national academic standards in math, science and English/Language Arts. A unified STEM Academies-CTE program could help to advance this pass rate closer to the program's 100% goal. An additional strength of current CTE programming is its offering of work-based learning opportunities such as job shadowing, clinical practicums, and internships, which allows students to learn about and reinforce the technical skills necessary for employment in the workplace. A unified STEM Academies-CTE program could leverage these work-based learning opportunities in such a way that students could engage in intense experiences that showcase their mastery of content knowledge, analytical and synthetic thinking, and technical skills in the pursuit of either highly valuable industry credentials or outright postgraduate employment.

A UNIFIED STEM ACADEMIES-CTE PROGRAM & RECLAIMING COMPREHENSIVE HIGH SCHOOL IDENTITY

Many of the SDP's comprehensive high schools, unlike their special admission or magnet counterparts, do not always have an explicitly articulated identity independent of their school's official mission statement. As such, their identities are derivative of community history and contemporary perspectives. Moreover, because many of the SDP's comprehensive high schools are decades (or even over a century) old, it is conceivable that several generations of a community or a family are graduates of any given institution.

However, the rise of charter schools in the SDP within the past 20 years has started to challenge the community-neighborhood school link that has long anchored these comprehensive high schools. Many charters have adopted some external identity, as embodied in their founding charters, with the intent of filling some perceived niche that attempts to appeal beyond the traditional neighborhood school zone. For instance, several charters have engaged in a (quasi) CTE-based model (e.g., Charter High School for Architecture & Design, Philadelphia Electrical and Technology Charter School, Mathematics and Science Technology Charter) all with varying degrees of success. Their allure has been curricular offerings that seek to focus on an explicated articulated identity while simultaneously offering a college preparatory curriculum. These schools have staked a claim in the broader Philadelphia education landscape by seeking to specialize in fields while admitting students absent some admission criterion frequently associated with special admission and magnet schools. However, two possible reasons for their highly variable performance have been (1) the lack of community engagement and (2) issues associated with scalability. (Lawton, 2009; Warren et al., 2009) It is possible then for a unified STEM Academies-CTE program to address both issues to develop explicit identities for the SDP's comprehensive high schools.

To the first point, because charter schools admit students from all zip codes in the City of Philadelphia, they have a diverse student body that may not necessarily have an allegiance to any single neighborhood as would the case with a comprehensive high school. Moreover, given the charter movement's relative youth compared to decades (or even over a century) old SDP traditional neighborhood schooling, they are at a disadvantage when cultivating a long-standing rapport with the community. However, a unified STEM Academies-CTE program *tailored to the needs of a specific neighborhood* and *housed in that neighborhood school* would allow the SDP to leverage existing partnerships (as well as develop new ones) that would support academic programming in these schools. For instance, West Philadelphia High School already has a well-developed automotive engineering program and, with multiple automotive-related facilities (e.g., garages, part shops, dealerships) in the West Philadelphia area, students can engage in SDP sanctioned internships designed to complement their conceptual knowledge. This relationship not only benefits students in these programs but also promotes a positive image among the community they serve.

To the second point, most charter schools cannot scale their operations in a single area of the City let alone throughout since many of them function either as standalone schools or as part of a limited size network. Thus, a unified STEM Academies-CTE program might ultimately create a districtwide network of comprehensive schools that are both connected to their communities and have a particular STEM-CTE focus area. While a college preparatory curriculum has been and will continue to be a mainstay of the SDP's academic programming, each comprehensive high school would ideally house a supplementary STEM-CTE track. It is important to note that this vision does not dissolve the mandates of specific special admission and magnet schools (e.g., High School for Creative and Performing Arts, Philadelphia High School for Girls) as these schools will continue to engage in academic programming that seeks to fulfill its mission. Interestingly, however, their mandate does provide the imprimatur for specific STEM specialized programs that might otherwise be possible to scale such as computer-based animatronics or the "Girls Who Code" curricular offerings. However, what this approach does provide is for many of the SDP's comprehensive highs schools that have not had an explicit identity or mandate to develop one that allows them to compete on par with charter schools for students without infringing (and, by extension, competing) with the identity or mandates of other SDP schools.

RESOURCES & PARTNERSHIPS

Educational leadership is complex and demanding, and its execution requires a leader to be equal parts, pedagogical leader and organizational manager. This penultimate section seeks to outline a comprehensive approach to STEM Academies Initiative's philosophy of organizational management, as demonstrated in **FIGURE 1.5**. It is important to note that this report intentionally devoted considerably more text to pedagogical leadership and only now discusses the role of organizational leadership since research has shown that in the absence of the former, the latter can lead to a waste of time, energy, and resources. (Fullan, 2007; Loucks-Horsley et al., 2009; Marzano, Waters, and McNulty, 2001) Thus, educational leadership absent a sound pedagogical approach grounded in theory and supported by research degenerates into organizational management that only propagates the status quo.

As with any elaborate enterprise, identifying resources and partnerships, both internally and externally, are essential to not only the design and strategic implementation of an initiative but also its adoption and success. Of course, resources, no matter how numerous, require a degree of husbandry if at least to convince stakeholders that the managers of these resources demonstrate good stewardship. Likewise, relationships, which are grounded in mutual goals, involve a mixture of collaboration and education leadership in which one party leans on the other for guidance, (public and private) support and, of course, the sharing of resources. Additionally, relationships are highly dependent on non-tangible factors such as trust and respect; management then of resources and partnerships requires that the coordinating party – in this case, the SDP – possess a clear vision for a proposed program's intent and goal. (Bryk et al., 2010)

MARSHALING INTERNAL RESOURCES

Although the SDP's reserve of internal resources has substantially improved in the past decade, it would be erroneous to assume that these resources are infinite and therefore can be used to fund programming without pedagogical visions (e.g., a trial-and-error based approach to resource allocation). Such an approach would undeniably require a large pool of resources (financial, human, or otherwise) that is capable of underwriting unsuccessful initiative(s). Few would deny that urban districts, particularly in Pennsylvania, have lees resources per student (as evidenced by per-pupil spending) than their wealthier suburban counterparts. Consequently, it comes as no surprise then that suburban STEM specialty schools both within and outside the state, such as Downingtown STEM Academy (Downingtown, PA), the Bergen County Academies (Hackensack, NJ), and the Middlesex

Country Academies in Science, Mathematics, and Engineering Technologies (Edison, NJ), consistently rank amongst the top STEM high schools *nationally*. Thus, the SDP will need to first marshal internal resources before approaching outside parties to supplement its needs with the intent of balancing its finite resources with the ambitious goals enshrined in the STEM Academies Initiative.

Financial & Material. In the past few years, the SDP has made STEM education a major academic priority considering the Governor's and Mayor's more extensive economic plans to promote a college and career-ready workforce. In turn, this prioritization has led to new financial and material investments in the SDP designed to foster new initiatives as well as infuse additional financial resources and technologies into its core academic programming. Consequently, the SDP engages with multiple organizations (profit, non-profit; local, regional, national) to assist in developing its long term approach towards STEM education. Several of these partnerships, such as LEGO Education (directed by the OCIA) and Code.org (led by the OET), have already been implemented in some of the SDP's schools and will be assets to the STEM Academies Initiative, particularly during the initial phase of the strategic implementation process. The efficient and economical use of existing resources would not only accelerate the logistical implementation of the STEM Academies Initiative but also harness teacher and student familiarity with contemporary programming to spur involvement on the part of teachers and students in the Academies' new curricular and instructional approach.

Of course, scaffolding these resources such that they complement the proposed curricular and instructional framework outlined in Figure 1.3 requires a high degree of internal district coordination both at the Central Office and Building level. At the Central Office level, the OHSS will use the initial design phase of the Academies' life cycle to not only research the current battery of STEM-related programming but also communicate ways in which the STEM Academies Initiatives can augment contemporary projects in peer offices. The symbiosis of such an approach would extend beyond program efficiency (e.g., eliminating redundancies in resource allocation), demonstrating to stakeholders that the STEM Academies Initiative is one that seeks to become a permanent feature of the SDP's academic vision, ultimately increasing its chances for long-term viability. (This viability is essential for the scaling process so that implementation of the STEM Academies Initiative is consistent wholly across the district.) Moreover, at the Building level, and especially prior to the piloting phase, the OHSS will actively engage with those Assistant Superintendents and principals who are (1) keen to reap the benefits of the STEM Academies model in terms of student engagement and achievement and (2) committed to supporting the program's initial cohort of teachers and students.

Perhaps it goes without saying that the success of the STEM Academies Initiative rests on its financial support within and outside the SDP. Internally, the Chief Academic Officer has committed to a budget for the pilot implementation during SY2020-21 with necessary adjustments in the subsequent years based on outcomes and feedback received during the piloting process. Ideally, these monies would sustain reoccurring expenditures, such as the potential hiring of new staff and ongoing contracts with selected vendors, so that the SDP can manage these costs based on the district's short- and long-term financial outlook. Supplemental

monies via grants, however, would best be used for singular or intermittent capital intensive investments such as the design or purchase of professional development, instructional resources, infrastructure, and course-related technologies.

Human Resources. Historically longstanding shortages in qualified teachers in mathematics, natural science (biology, chemistry, and physics) as well as computer science have traditionally proven to be obstacles towards the development of a comprehensive STEM education program, particularly in hard-to-staff urban schools. Between 2013 and 2016, Title II Higher Education data (U.S. Department of Education, 2018) shows that Pennsylvania has experienced precipitous declines in the number of certifications issued in core STEM subject areas (Biology: 52%, Mathematics: 63%, Chemistry: 74%, and Physics: 78%) while simultaneously grappling with changes in demography, school funding, and school evaluation protocol. As the prominence of STEM education continues to grow, especially for college and career readiness, districts are continuously reconciling a perennial STEM teacher shortage with an ever-changing climate of education policy and broader socioeconomic need.

However, the SDP does have some considerable human resources than can be engineered to assist in the development and implementation of the STEM Academies Initiative. In terms of engaging pre-service STEM teachers, the SDP already has partnerships in the Greater Philadelphia region, one that is known for its high concentration of post-secondary institutions, that can be leveraged to supply STEM Academies with teachers who are eager to engage students in the proposed curricular and instructional framework. Sutcher, Darling-Hammond, and Carver-Thomas (2016) and Ingersoll (2001) have argued that nearly 70 percent of urban math and science teachers and 50 percent of all new teachers, respectively, tend to leave urban teaching within the first five years. Therefore, the STEM Academies Initiative will need to partner with the Office of Teaching and Learning to ensure that these novice teachers receive a high level of building-level and district-level mentorship as well as classroom support that extends beyond the initial induction period.

While implementing extensive STEM teacher supports can help *retain* new teachers, this approach does not directly address what has become a nationwide shortage of certificated STEM teachers. For instance, the same Title II Higher Education data indicates that *less than 100* teachers were certified in Physics 7-12 *statewide* in Pennsylvania during the 2015-16 academic year. Such a meager supply suggests that these newly minted teachers might have been enough for replacement level needs (e.g., maternity leave, retirement, sabbaticals) but hardly enough to effectively augment preexisting programs – let alone one in the state's largest school district. While it is quite challenging to have a non-certificated teacher teach as an instructor of record in a core course, one possibility is to engage CTE teachers in the development and teaching of *elective* courses. CTE teachers, by their experience and vocational certification, already have an intuitive understanding of how principles of mathematics and science manifest in a multitude of technology and engineering fields. For instance, it stands to reason that a plumber likely has familiarity with the concept of fluid dynamics while someone with a background in food sciences probably has a working knowledge of biochemistry. These teachers, in turn, can be supported with professional

development, instructional resources, and building level support that would allow them to supplement their practical knowledge with the underlying theoretical knowledge necessary for students to engage in the analytical and synthetic thinking skills essential to grade-level STEM engagement.

Lastly, this approach to outfitting teachers who have an extensive background in one field with the content and skills needed to engage students in a related field is not an entirely new concept. Instead, it has precedence in the field of computer science since many states do not have guidelines for obtaining formal teacher certification in the area. In Pennsylvania, teachers who possess certifications in a variety of fields such as Mathematics, the Natural Sciences, Technology Education; and Business, Computer and Information Technology, can serve as teachers of record in computer science courses. In the case of these adaptive computer science teachers, the state has offered several grants and professional development related opportunities to create a nascent supply of professional computer science teachers.

GRANT FUNDING. NON-PROFITS, AND THIRD-PARTY VENDORS

There is no doubt that such an ambitious approach will require an infusion of capital to at least develop and pilot the programs before incorporating them as a mainstay of the SDP's academic programming. Fortunately, given the centrality of Philadelphia as an economic hub along the Northeastern (I-95) Corridor, a plethora of organizations have expressed their support for improving STEM education both at the national, regional, and local levels. At the national level, non-profit foundations such as the Alfred P. Sloan Foundation, the Carnegie Foundation of New York, and the Howard Hughes Medical Institute have committed millions of dollars to improve K-12+ STEM education, with additional monies set aside for improving STEM education (and retention) for traditionally under-represented students. Several private organizations, such as the Boeing Corporation, Dow Chemical, and GlaxoSmithKline – all of which have a significant presence in the Greater Philadelphia area – are equally committed to financially and logistically supporting STEM education, particularly in urban settings. At the state level, current Governor Tom Wolf (D) has committed state funds to districts to bolster their STEM college and career readiness programs, particularly in urban schools, as has current President Donald Trump (R). This show of bipartisan suggests that funding improvements in STEM education are more than improving academic outcomes; it is also about educating a more productive workforce that can compete globally. Given that the SDP has a well-developed grant procurement apparatus in the Office of Grant Development as well as a robust philanthropic outreach arm in the Fund for the School District of Philadelphia, the STEM Academies Initiative is an ideal venue for STEM education-minded philanthropists.

Non-profits also have the potential to engage in the STEM Academies Initiative by providing on-demand services guided by SDP needs. For instance, the Philadelphia Education Foundation (PEF) has established a STEM Ecosystem, part of a more extensive national system of such organizations, in which various stakeholders come together in working groups to address the socioeconomic barriers and potential gaps that hinder access and equity in STEM education. PEF's STEM Ecosystem can be a potential tool in helping the STEM Academies

Initiative cultivate community partnerships necessary for SDP graduates to pursue extracurricular and post-secondary STEM opportunities. Likewise, institutions of higher education (IHEs) can also serve as equally valuable resources in the development of this initiative by supporting the work of our students, teachers, and the OHSS. For instance, Temple University's TUteach program works closely with the SDP to address the shortage of STEM teachers in the district. Furthermore, the University's College of Engineering hosts the Mathematics, Engineering & Science Achievement (MESA) program, which offers teachers and students academic opportunities to engage in a team-based approach to an anabolic application designed to service the needs of local communities. Lastly, third-party vendors, too, can play an assistive role in the development of the STEM Academies Initiative. As discussed at the beginning of this report, teachers will need several avenues of support that will prepare them for pedagogical success, such as professional development, instructional resources, equipment, and even logistical support. Several vendors such as Project Lead the Way, DefinedSTEM, and LEGO Education provide either one-time or reoccurring services that could potentially meet and sustain the STEM Academies programming needs in the immediate, short, and long-term.

In all these partnerships, it is critical to keep in mind that the SDP is the directing agent for these parties as their participation is dependent on the *needs of* the STEM Academies Initiative. Grant-providing agencies, especially those who award large sums for systemic change, generally require recipients to outline a meticulous and methodological approach with clear implementation protocol as well as accountability measures for success. Because partnerships with IHEs and non-profits and, of course, third-party vendors may rely on compensation for external services, leaders in STEM Academies Initiative will need to ensure that procurements match expenditures justified by programmatic needs. Thus, it is incumbent on the STEM Academies Initiative's leadership to act as both responsible and economic stewards of these funds so that they *directly* support building level activity designed to improve outcomes in student achievement and growth (PVAAS). In short, given the SDP's primary responsibility for improving student achievement, particularly on state and federal accountability measures in STEM, it must play an *active* role in funding and partnerships rather than taking a *passive* one.

AVENUES FOR STAKEHOLDER PARTICIPATION

While the SDP, and particularly the OHSS, is ultimately the evaluated party relating to the program's success and failures, the scale of the project and partnerships involved does necessitate the need for stakeholder participation. Given the need for a cohesive and coordinated approach to the STEM Academies Initiative as noted in the preceding pages, the Deputy Chief will serve as the administrative contact who oversees the directive and managerial aspects of the program (e.g., finalizing policy and purchases, directing resources human and financial). Additionally, the Assistant Director of STEM will serve as the principal investigator for the STEM Academies Initiative with oversight over the logistical aspects of the program (e.g., developing curriculum and instruction, supporting building level faculty and staff). The rationale for this division of labor is both conceptual and practical. Conceptually, parties interested in financially supporting the STEM Academies Initiative often mandate the

recipient of this funding to provide periodic updates that specify not only how funding is allocated and spent, but also the link between expenditures and articulated program outcomes. In turn, these granting agencies are accountable to their respective stakeholders, who have the executive power to continue or modulate their support. Thus, it may be difficult for either individual to address both requirements at a level that is satisfactory to the granting agency. Practically, the Deputy Chief oversees several projects in her portfolio that may require varying degrees of time, human resources, and administrative coordination across the office wholly whereas the Assistant Director of STEM is responsible for specific oversight of only the STEM Academies Initiative.

Additionally, research has shown that while some initiatives may have (and even require) a top-down implementation do achieve success in the beginning stages, particularly in establishing the program's critical foundations, few of these programs are sustained with fidelity in the long term without input from stakeholders. (Bryan & Henry, 2012; Fredricks & Eccles, 2006) To that end, the STEM Academies Initiative will include three avenues of stakeholder participation that will act as governance advisory bodies.

Academies Advisory Committee. This group is a Central Office-level Committee, comprised of Director level staff, that guides the development of (formal and informal) STEM policy via collaboration between internal departments. Consequently, this group would research professional development opportunities, discuss potentially fruitful collaborative initiatives with IHEs, and identify grants that might support the work of the Academies.

Academies Support Committee. This group is a Building-level Committee, comprised of STEM teachers (curricular and instructional experts) and school leaders (administrative supports), which will be responsible for guiding the OHSS on the logistics of implementation. Consequently, this group would advise on matters related to curricular and instructional needs, develop approaches to gauging and monitoring teacher and student participation in the STEM Academies Initiative, and offering the OHSS potential solutions and avenues for troubleshooting at the school (and grade) level.

Academies Liaison Committee. This group is a Community-level Committee, comprised of grant funders as well as internal and external agents who wish to actively promote the STEM Academies Initiative within and outside the SDP. This group will develop external partnerships between stakeholders that provide opportunities for students to engage in STEM work beyond the school day and calendar. Moreover, this group will also advise the OHSS on potential extracurricular opportunities for students (e.g., competitions, attending and hosting events) that serve to improve STEM engagement as well as the external support for the STEM Academies Initiative.

STEM Education and the Promise of Equity & Access

In conclusion, a commitment to a rigorous STEM education requires a series of internal alignments and external collaboration, especially in the context of one of the largest urban school districts in the country. Annual data from the U.S. Census Bureau repeatedly ranks the City of Philadelphia as the poorest amongst the top 10 largest cities in the country, as evidenced by the poverty rate. However, the Greater Philadelphia region (Philadelphia-Camden-Wilmington Metropolitan Statistical Association) has the eighth largest GDP output in the nation ($445 billion). Such a disparity suggests both the promise and challenges inherent in improving STEM education. (Howell, 2018) Moreover, the history of urban schooling provides ample evidence for the assertion that districts and their constituent communities enjoy a reciprocal relationship with community members such as IHEs and businesses dependent on schools to prepare students for post-secondary college and career options and schools formulating intra- and extra-curricular programming and policy to meet those demands. However, as discussed above, the success of these programs requires communities to *participate actively and invest in* a comprehensive and cohesive vision of STEM education.

However, apart from the economic role of STEM education so often touted by stakeholders, it has social and pedagogical value, especially for marginalized groups in the STEM fields such as historically underperforming students (African-American, Hispanic, English Language Learners, and Special Education students) and women. As the research above argues, these students have a history of placement in less rigorous learning environments, which are often characterized by diluted standards of teaching and learning. Moreover, during their formal schooling, many female students interested in pursuing STEM internalize gender norms that insinuate a rigorous STEM education is the exclusive domain of their male peers. (Steinke, 2007) Today, the demographic constitution of many STEM fields illustrates an alarming lack of minority and female representation due to, in part, the obstacles these students face in the educational process. Research regarding the achievement gap, particularly in STEM education, consistently notes that instructional quality is one of the greatest influencers of student achievement for the marginalized students (Borman & Kimball, 2005; Johnson, Kahle, and Fargo, 2007; Desimone & Long, 2010). For instance, nontraditional approaches to teaching and learning that reinforce both conceptual and practical engagement encourage these marginalized students to develop stronger memory, logic, and self-efficacy skills – all of which are highly prized in any post-secondary path let alone in the STEM fields. Thus, STEM education is arguably the most comprehensive approach to achieving equity and access to high-quality teaching and learning in urban schools. If a school's STEM curriculum is a barometer of its VA and HA, and if educating traditionally marginalized students is a gauge of a school's instructional quality, then it stands to reason that **improvements in STEM achievement for marginalized students are the most definitive measure of a school's overall academic excellence.**

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REPORT FIGURES

Figure 1.1: Office of High School Supports Framework for Instructional Rigor in STEM Academies

FOCI	STRATEGY	STUDENTS	TEACHERS/STAFF	SCHOOL LEADERS	CENTRAL OFFICE
Instructional Rigor: Science, Technology, Engineering and Mathematics: Grades 6-12	STEM Academy Next Generation Science Standards (NGSS)	Students in grades 6-12 will participate in STEM education based on NGSS standards and innovative thinking in science, math, technology and engineering with embedded 21st century skills.	Provide an integrated, interdisciplinary, and student-centered approach to learning that encourages curiosity, creativity, artistic expression, collaboration, computational thinking, communication, problem solving, critical thinking, and design thinking for the 21st century.	Monitor and support the instruction of the STEM curriculum, student engagement, productivity and output that equips students with the knowledge and skills necessary to enter the workforce and be successful in a technology-driven, global economy.	Develop and implement a cohort based STEM academy in middle grades and high schools. Provide logistical and instructional supports to school-based staff.

Figure 1.2: Schema Relating the Progression of Skills in Preparation for (Post-Secondary) STEM College & Career Readiness

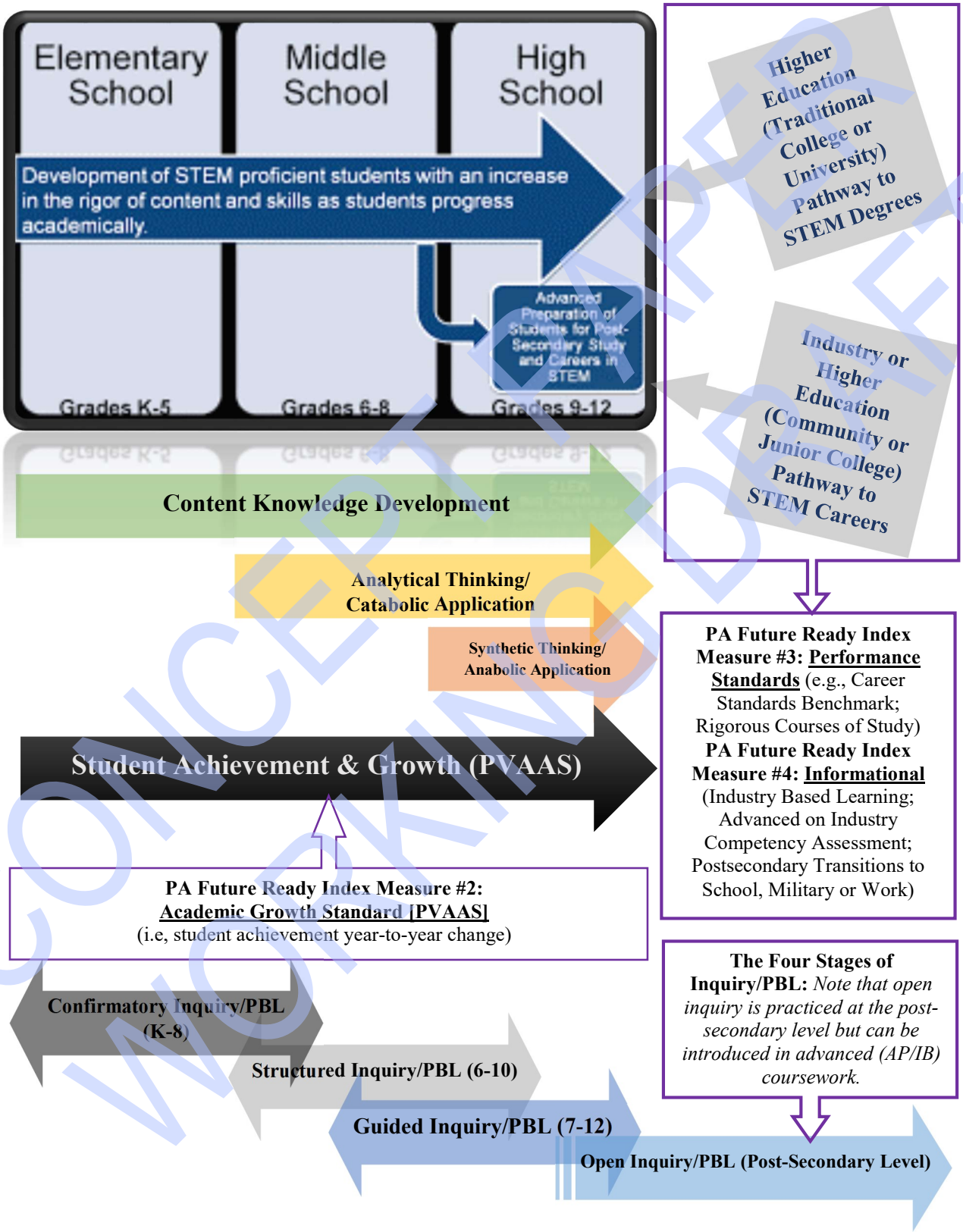

Figure 1.3: Proposed Progression of Coursework in STEM Academies

Core Subject Area	Primary Years (Grades K-5)	Early Secondary Years (6-8)	Late Secondary Years (9-12)		Post-Secondary Level STEM Coursework
			Grade Level STEM Programming	*Advanced Level STEM Programming*	
STEM Skill Focus (See Figure 1.2)	*Content Development*				
		Analytical Thinking + Catabolic Application			
			Synthetic Thinking + Anabolic Application		
Inquiry/ Problem-Based Learning Stage (See Figure 1.2)	*Confirmatory Inquiry*				
		Structured Inquiry			
			Guided Inquiry		
					Open Inquiry
Science	Development of Scientific Vocabulary and Processes (e.g., cells and organs, atoms and compounds, simple machines)	Earth & Space Science (e.g., Geology, Astronomy) **[Grade 6]** Physical Science I: Conceptual Chemistry (e.g., Cehmical Reactions, Periodic Table) **[Grade 7]** Physical Science II: Conceptual Physics (e.g., Gravity and Force; Energy) **[Grade 8]**	Environment Science **[Grade 9]** Biology **[Grade 10]** Chemistry **[Grade 11]** Physics **[Grade 12]**	Biology **[Grade 9]** Chemistry **[Grade 10]** Physics **[Grade 11]**	AP/IB Biology; AP/IB Chemistry IB Physics; AP Physics (1 & 2: Algrebra Based) AP Physics (C: Mechanics; Calculus Based); AP Physics (C: Electromagnetism; Calculus Based) AP Environmental Science; IB Nature of Science
Computer Science (Technology)	Digital Literacy	Computer Science Discoveries I: Elements of Computing (e.g., Hardware, Software, Firmware) **[Grade 6]** Computer Science Discoveries II: The Internet of Things (e.g., Computer Networking; Elementary Coding in HTML/CSS) **[Grade 7]** Computer Science Discoveries II: Introduction to Coding (e.g., Mobile Applications, Animations, and Games; Scratch/Blockly) **[Grade 8]**	AP Computer Science Principles; IB Design Technologies **[Grade 9-10]** AP Computer Science A**;** IB Computer Science **[Grade 10-11]**		Introduction to Machine Learning & Artifical Intelligence Introduction to Robotics
Engineering	Development of Engineering Concepts and Terminology (e.g., relationship between structure and function, types and uses of machinery)		*Career & Technical Education:* **Transportation Pathway:** Automative Technology & Logistics **Bio-life Pathway**: Animal/Veterinary & Horticulture **Health Pathway:** Medical, Dental, and EMT **Trades Pathway:** Construction & Manufacturing **Information Technology Pathway:** Computer Systems & Web Design	Aero & Automotive Engineering **(Transportation Pathway Alt.)** Agro-Environmental Engineering **(Bio-Life Pathway Alt.)** Biochemical Engineering **(Health Pathway Alt.)** Civil Engineering **(Trades Pathway Alt.)** Computer Engineering **(Information Technology Pathway Alt.)**	
Mathematics	Development of Numeracy and Computational Skills	Mathematics Enrichment **[Grade 6: CP Only]** Logic & Reasoning **[Grade 7: CP; Grade 6: H)]** Pre-Algebra **[Grade 8: CP; Grade 7: H]**	Algebra I **[Grade 9]** Geometry **[Grade 10]** Algebra II **[Grade 11]** Pre-Calculus /Trig. **[Grade 12]**	Geometry **[Grade 9]** Algebra II **[Grade 10]** Pre-Calculus /Trig. **[Grade 11]**	AP Calculus (AB/BC) AP Statistics
English/Language Arts	Fiction-Based Reading & Writing/ Vocabulary Development	Non-Fiction Based Reading & Writing/ Vocabulary Development	Adv. Non-Fiction Based Reading & Writing/ Vocabulary Development	Technical Reading & Writing/ Vocabulary Development	AP Research; AP Seminar IB Philosophy

Requires Coordination and/or Development with Office of Curriculum, Instruction, and Assessment

Requires Coordination and/or Development with Office of Educational Technology

Requires Coordination and/or Development within Office of High School Supports

Figure 1.4: Proposed STEM Academies Development & Implementation Timeline

Figure 1.5: Schemata of the STEM Academies Initiatives Organizational Environment