K-12 STEM Education Overview

In this report, Hanover Research provides an overview of K-12 STEM education. The first section of this report provides a definition of STEM as it relates to K-12 education. The second section discusses best practices in STEM initiatives including program communication, structure, implementation, and sustainability. The third section of the report discusses professional development for STEM educators. The final section of the report details exemplary elementary and secondary STEM school models.
Executive Summary

This report provides an overview of K-12 education in science, technology, engineering, and mathematics (STEM). The report is organized according to the following four sections:

- **Section One**: provides a comprehensive definition of STEM and discusses its importance for K-12 education.
- **Section Two**: discusses best practices in STEM initiatives including program communication, structure, implementation, and sustainability. This section includes information from a survey of over 200 STEM secondary schools in the United States.
- **Section Three**: highlights best practices in professional development for STEM educators and offers examples of professional development opportunities.
- **Section Four**: describes various model STEM programs throughout the country including schools at the elementary and secondary levels. Hanover provides examples of both selective and inclusive STEM-focused schools. These schools demonstrate many of the best practices discussed in Section Two of this report.

Key Findings

Here, we provide a brief overview of the key findings found throughout this report. The findings are organized according to the sections of this report.

**STEM Definitions**

- STEM is a broad reform movement in the area of science, technology, engineering and mathematics that seeks to cultivate a STEM-proficient workforce and a STEM-literate citizenry to increase the United States’ competitiveness in the global economy.

- Increasingly, definitions of STEM also include reference to an interdisciplinary approach that aims to cultivate a deeper understand of each subject through an emphasis on the interrelated nature of science, technology, engineering, and math.
Best Practices: Program Communication, Structure, Implementation, Sustainability

- There is a need to increase awareness among parents and students concerning the importance of STEM education. The following three messages are most likely to resonate positively with the community: (1) STEM education prepares all students for the challenges and opportunities in the 21st century economy; (2) STEM education improves the impact and overall effectiveness of the K-16 education system; and (3) A STEM-literate workforce adds value, productivity, and innovations to the economy.

- STEM-focused schools find innovative methods for structuring the curriculum, develop new instructional techniques, recruit highly-qualified teachers, provide opportunities for extracurricular activities, and foster connections with the professional STEM community. Implementation should include careful research, a long planning process, and a detailed blueprint of the STEM program.

- STEM education should begin in elementary schools because this is when interest in science and math is typically developed.

- A coherent and rigorous curriculum that focuses on depth rather than breadth is essential for any successful STEM school initiative. Pedagogical techniques used in STEM-focused schools include project-based learning, workplace or lab-based learning, the use of technology-supported learning tools, as well as traditional, teacher-led instruction.

- One way to motivate students and cultivate student interest in STEM subjects is to offer various extracurricular activities to students. Such activities may include summer programs, afterschool enrichment activities, science fairs or Olympiads, and other competitions.

Professional Development Opportunities

- Professional development for STEM teachers should persist over an extended period of time. Surveys of teachers suggest that teachers were most interested in STEM-focused professional development that emphasized career awareness, inquiry based activities, and interdisciplinary activities. Visits and tours or workshop activities were the most preferred modes of delivery.

Model Programs

- This report provides an overview of the following model programs, all of which provide examples of the best practices in program structure and
pedagogy identified through the literature. In particular, project-based and inquiry-based learning, and the availability of a range of innovative extracurricular courses were common among the STEM-focused schools.

- Illinois Mathematics and Science Academy (selective high school)
- Thomas Jefferson High School for Science and Technology (selective high school)
- High Tech High (inclusive high school)
- Oakcliff Traditional Theme School (inclusive elementary school)
STEM Definitions

Introduction

American high school students rank alarmingly low among students of industrialized countries when it comes to achievement in science and mathematics. The poor performance of American students in the vital fields of science, technology, engineering, and mathematics (the STEM fields) is a fact borne out in test scores and other assessments of academic achievement. Nationally, only about a third of American students in grades 4 and 8 performed at or above proficient in these subjects, while more than a third scored below the basic level in mathematics and science on the National Assessment of Educational Progress in 2009. In grade 12, only a quarter of students performed at or above proficient in mathematics.

These alarming trends have led to the formation of a broad reform movement encapsulated by the acronym “STEM.” This acronym was first used by the National Science Foundation (NSF) to refer to programming dealing with science, technology, engineering, and mathematics. Although the NSF was the organization to develop this acronym, it did not provide an explicit definition of “STEM.” This has led to the existence of differing definitions and operational applications across the nation and within organizations. Though these definitions are not necessarily incompatible with each other, multiple interpretations have created confusion among many educators.

Goals of STEM Education

An appropriate understanding of STEM begins with an examination of its intended outcomes. Generally speaking, these goals are designed to increase America’s global competitiveness in science and technology innovation as well as to improve the STEM understanding of all U.S. citizens. The President’s Council of Advisors on...

---

4 Ibid, p. 3.
Science and Technology (PCAST) identifies four major goals of STEM Education, examined in the table below.\(^5\) By keeping these objectives in mind, educators can develop a set of practices intended to meet these specific goals.

**Table 1.1: Goals of STEM Education**

<table>
<thead>
<tr>
<th>Ensure a STEM-capable citizenry</th>
<th>Build a STEM-proficient workforce</th>
</tr>
</thead>
<tbody>
<tr>
<td>❖ This goal seeks to cultivate a citizenry that has “the knowledge, conceptual understandings, and critical-thinking skills that come from studying STEM subjects.” This is important even for those who never directly enter a STEM-related career.</td>
<td>❖ This goal seeks to adequately prepare a sufficient number of workers for job openings in STEM-related careers which are expected to increase in coming years. Additionally, STEM-related skills are increasingly relevant in fields not directly related to STEM subjects.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cultivate future STEM experts</th>
<th>Close the achievement and participation gap</th>
</tr>
</thead>
<tbody>
<tr>
<td>❖ This goal aims to educate the best STEM experts in the world because they contribute “to economic growth, to technological progress, to our understanding of ourselves and the universe, and to the reduction of hunger, disease, and poverty.”</td>
<td>❖ This goal aims to increase women and minority participation and interest in STEM fields in order to tap into the country’s full potential.</td>
</tr>
</tbody>
</table>

Source: PCAST

**STEM Subjects and Skills**

Taken literally, the acronym “STEM” stands for science, technology, engineering, and mathematics. In the realm of K-12 education, STEM typically refers to coursework related to these disciplines. However, each of these categories may include instruction in several subject areas. The following table outlines common STEM subjects in K-12 education:\(^6\)

**Table 1.2: Relevant STEM Subjects**

<table>
<thead>
<tr>
<th>Science</th>
<th>Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>❖ Biology</td>
<td>❖ Computer/Information Systems</td>
</tr>
<tr>
<td>❖ Chemistry</td>
<td>❖ Game Design</td>
</tr>
<tr>
<td>❖ Marine Biology</td>
<td>❖ Developer</td>
</tr>
<tr>
<td>❖ Physics</td>
<td>❖ Web/Software Developer</td>
</tr>
<tr>
<td>❖ Science</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Engineering</th>
<th>Mathematics</th>
</tr>
</thead>
<tbody>
<tr>
<td>❖ Chemical Engineering</td>
<td>❖ Mathematics</td>
</tr>
<tr>
<td>❖ Civil Engineering</td>
<td>❖ Statistics</td>
</tr>
<tr>
<td>❖ Computer Engineering</td>
<td></td>
</tr>
<tr>
<td>❖ Electrical/Electronic Engineering</td>
<td></td>
</tr>
<tr>
<td>❖ General Engineering</td>
<td></td>
</tr>
<tr>
<td>❖ Mechanical Engineering</td>
<td></td>
</tr>
</tbody>
</table>

Source: STEMconnector

---

http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-stem-ed-final.pdf

In addition to these subjects, STEM may also include instruction in environmental science and geology.\(^7\) Though certain social and behavioral sciences (such as economics, anthropology, and sociology) may be appropriate STEM subjects at the postsecondary level, they are not typically addressed in K-12 education.\(^8\) Furthermore, most definitions of STEM education do not include references to the medical fields.

Traditionally, math and science have been emphasized more than technology and engineering in practical applications of STEM.\(^9\) For example, the National Assessment of Education and Progress measures these traditional subjects (e.g. math and science), but not technology or engineering. Proponents of STEM education advocate increasing the visibility of technology and engineering in the standard K-12 curriculum. Contrary to popular belief, technology education includes more than just incorporating computer literacy into the curriculum. Technology relates to the way in which humans have developed tools to modify the natural environment and therefore the definition of technology education should be “expanded to include all kinds of devices, instruments, and tools that can be applied in both domains of science and engineering.”\(^10\)

In addition to developing content knowledge in these areas, STEM education also seeks to cultivate soft skills such as scientific inquiry and problem-solving skills.\(^11\) By enhancing these skills, STEM education seeks to build a STEM-literate citizenry. This “STEM literacy refers to an individual’s ability to apply his or her understanding of how the world works within and across four interrelated domains.”\(^12\) The following table defines STEM-literacy according to each of the four subject areas.\(^13\)

\(^8\) Ibid.
\(^13\) Ibid.
Table 1.3: Defining STEM Literacy

<table>
<thead>
<tr>
<th>Scientific literacy</th>
<th>• The ability to use scientific knowledge and processes to understand the natural world as well as the ability to participate in decisions that affect it</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technological literacy</td>
<td>• Students should know how to use new technologies, understand how new technologies are developed, and have the skills to analyse how new technologies affect us, our nation, and the world</td>
</tr>
<tr>
<td>Engineering literacy</td>
<td>• The understanding of how technologies are developed via the engineering design process using project-based lessons in a manner that integrates lessons across multiple subjects.</td>
</tr>
<tr>
<td>Mathematical literacy</td>
<td>• The ability of students to analyze, reason, and communicate ideas effectively as they pose, formulate, solve, and interpret solutions to mathematical problems in a variety of situations</td>
</tr>
</tbody>
</table>

Source: National Governor’s Association Center for Best Practices

Finally, proponents of STEM education are increasingly advocating the interrelated nature of all the STEM subjects and the necessity of implementing an interdiscipli


"silos." The following figure demonstrates this concept by illustrating some of the connections between the subjects.14
Figure 1.1: Value of an Interdisciplinary Approach

Source: The Thornburg Center for Space Exploration
Best Practices: Communication, Structure, Implementation, and Sustainability

An increasing number of states are implementing initiatives to support the establishment of STEM-focused schools. SRI International provides the following definition of a STEM secondary school:\textsuperscript{15}

A STEM secondary school is a stand-alone school, school-within-a-school, or program providing secondary students (grades 9-12) with coursework that prepares them for higher education in science, technology, engineering, or mathematics fields.

Although STEM-focused schools such as Stuyvesant High School, founded in 1904, and the Bronx High School of Science, founded in 1938, are not an entirely new phenomenon, there has been a dramatic increase in the number of STEM-focused schools in recent years. Currently, 30 states have comprehensive programs for cultivating STEM education, and states such as Georgia, New York, Michigan, and Virginia have a particularly high concentration of these schools.\textsuperscript{16} A recent report found that there are at least 315 public STEM schools in the United States as of the 2007-2008 academic year.\textsuperscript{17} Eighty-six percent of these schools serve students in grades 9-12 while only 3 to 4 percent serve students in grades 1-5.\textsuperscript{18} These schools are increasingly focusing on underrepresented groups such as women and minorities.\textsuperscript{19}

STEM-focused schools can either be selective or inclusive. Selective schools base admissions decisions primarily on academic achievement and test scores whereas inclusive schools aim to educate a broader student population and base admissions decisions primarily on demonstrated student interest.\textsuperscript{20} Later in this report, we examine the program characteristics of these two types of STEM-focused schools.

First, however, we review the best practices in the areas of program communication, structure, implementation, and sustainability.


STEM Communication Strategies

In order for these STEM-focused schools to succeed and for the goals of STEM to be realized, there is a need to increase awareness among parents and students concerning the importance of STEM education. Public and parental support can help improve student achievement, but to do so, the barriers to effective communication must be overcome. These barriers include a lack of understanding of the connection of STEM education to economic development, a belief that advanced STEM courses are not necessary for students who do not intend to pursue STEM-related careers, and a belief that STEM is designed only for advanced students.

Because community support is essential for successful implementation of STEM Schools, the National Governor’s Association Center for Best Practices recommends the following three messages as those most likely to positively resonate with the community:

- **STEM education prepares all students for the challenges and opportunities in the 21st century economy:** In order to compete in the global economy, the next generation of students must have a strong knowledge of STEM – including an understanding of math, science, technology, engineering, problem-solving, and critical thinking skills – to succeed. Given that many U.S. students fall behind their international peers in mathematics and science assessments, the need for more rigorous education in STEM is clear.

- **STEM education improves the impact and overall effectiveness of the K-16 education system:** Rigorous STEM education can help increase student achievement in multiple subject-areas, as it helps to develop critical thinking and analytical skills. STEM education is an important contributor to college- and career-readiness.

- **A STEM-literate workforce adds value, productivity, and innovations to the economy:** STEM-literate workers create a culture of innovation in business and are important contributors to economic development.

According to a survey conducted by Harris Interactive, parents of K-12 students who were supportive of STEM education were more concerned with America remaining competitive and innovative in the global marketplace (about half of respondents) than with students having well-paying or fulfilling careers (about one third of respondents).

---

23 Quoted with slight variation from: Ibid, p. 16.
Program Structure

As more and more STEM schools are being developed across the nation, certain distinguishing design features emerge. STEM-focused schools tend to share the following four characteristics: 25

- Small size
- Project-based learning
- Integrated curriculum
- Focus on serving underrepresented students

SRI International conducted a survey of STEM-focused schools in the United States and responses from over 200 schools (out of 315 identified) reveal the most common academic structures being used. These results are organized according to the exclusivity of the school (inclusive or selective). The following figure displays the percentage of schools reporting to use each type of academic structure. 26

Figure 2.1: Academic Structures in Selective and Inclusive STEM Schools

![Academic Structures in Selective and Inclusive STEM Schools](chart)

Source: SRI International

Both types of schools primarily rely on traditional academic departments for structuring the STEM program. Both types of schools also tend to provide common planning time for teachers in order to support both professional development and increase interdisciplinary learning opportunities for students.

Finally, combining early college models with STEM school models can facilitate moving from one level of education to the next (i.e. from secondary to

---

postsecondary) and thus supports the STEM goal of developing a larger STEM-proficient workforce. STEM schools that use an early college model offer students college-level courses in high school. In some programs, students may graduate high school in five years with a high school diploma and an associate’s degree. Naturally, this type of program relies on partnerships with higher education. For example, North Carolina’s Learn and Earn early college high school provides a site at North Carolina Central University in Durham that offers college curriculum and work experiences with local biotech companies to provide students with an enhanced high school experience.27

**Instructional Techniques**

Research clearly indicates that **early and repeated exposure** to STEM subjects is essential for cultivating both future interest and future aptitude in STEM subjects.28 Thus STEM education should begin in elementary school and continue throughout secondary school.

Inclusive and selective schools appear to offer similar programs with comparable instructional techniques29 These common instructional techniques include:30

- Increased use of relevant, practical, application-based approaches
- Integration of content across disciplines from the early grades
- A focus on depth of learning and thinking as opposed to rote memorization

The unique characteristics of STEM subjects may require the use of alternative pedagogical techniques for effective communication of STEM concepts. Examples of **common pedagogical techniques** used in STEM-focused schools are:31

- Traditional, teacher-led instruction
- Project-based learning
- Workplace or lab-based learning
- Use of technology-supported learning tools

The STEM schools profiled later in this report provide examples of these types of pedagogical techniques “in action.”

---

The graph below displays the frequency of these techniques at STEM secondary schools. These data are based on identified secondary schools’ self-reported answers to a nationwide survey. Not surprisingly, lab-based science learning and technology-supported learning tools are extremely common.

**Figure 2.2: Frequency of Pedagogical Techniques in STEM Schools**

![Figure 2.2: Frequency of Pedagogical Techniques in STEM Schools](image)

Source: SRI International

**Curriculum**

Research clearly indicates that a coherent and rigorous curriculum is essential for any successful STEM school initiative. In some cases, actions have been taken at the state level to serve this goal. For example, 44 states (including Tennessee) and the District of Columbia have adopted the Common Core State Standards in Mathematics. This initiative seeks to replace diverse state curricula with standardized student learning goals in mathematics for grades K through 12. One of the goals of the Standards is to emphasize a depth of knowledge rather than focusing on a breadth of subjects. Research has demonstrated that students achieve higher academic standards when mathematics curriculum is infused with more depth.

---

37 Ibid.
The International Technology Education Association has crafted standards for technology education and literacy in grades K-12. The Standards for Technology Literacy (STL) offer a guide for age appropriate content knowledge and skills. The goal of this curriculum is to prepare technologically literate students who understand “what technology is, how it is created, and how it shapes society, and in turn is shaped by society.”

Massachusetts was the first state to create curricular guidelines and a framework for assessments in K-12 engineering education. This curriculum was developed with the assistance of the National Center for Technological Literacy at the Museum of Science in Boston. The organization is currently working with several states in the nation in order to develop similar standards across the country.

STEM schools also experiment with new models for delivering traditional courses. For example, the Physics First initiative in Rhode Island reorders the sequence in which high school students take science courses in order to more accurately reflect how students acquire knowledge. Under the proposed system students would first take physics followed by chemistry and then biology.

In addition to a coherent and rigorous curriculum, successful STEM school initiatives design and implement integrated curriculum content. As noted earlier in this report, STEM schools are increasingly introducing interdisciplinary techniques that thematically link one or several courses together. This strategy allows topics to “reinforce each other in support of the overall growth of each topic.” Currently, there is no widespread consensus on the necessity or methodology of interdisciplinary STEM education.

Motivating Students

Effective STEM instruction provides students with opportunities for hands-on experiences and real-world applications of scientific problems. One way to achieve this goal is by offering various extracurricular activities to interested students. Such activities may include summer programs, afterschool enrichment activities, science fairs or Olympiads, and other competitions. For example, IBM’s EX.I.T.E camps are directed at drawing underrepresented groups, particularly women, into the engineering profession. Targeting girls in middle school who may be interested in sampling engineering and technology careers, the camp is non-

---

residential and takes place near participants’ homes. The camps reach out to girls who show an interest in technology, but not necessarily a special aptitude. The logic behind this approach is that since many of the students are from backgrounds without extensive exposure to technology, they may not have had the necessary exposure to develop their skills prior to attending. Staffed by IBM women volunteers with technical backgrounds, the camp is also aimed at encouraging girls to continue taking math and science classes during high school. Since being founded in 1999, 6,400 girls have participated and 85 percent have indicated that they would consider pursuing an engineering or technical-related degree in college.45

Highly-Qualified STEM Teachers

Teachers with a strong capacity to teach in their discipline are essential for the success of any STEM school.46 These highly-qualified STEM teachers are in high demand, as STEM schools typically have low student to teacher ratios which average around 11 students to every one teacher.47

Innovative elementary schools have pioneered new methods of maximizing staffing resources at the elementary level. Because of the shortage of qualified math and science teachers at this level, a group of schools in California (led by Rocketship Education) developed a method where teachers with extensive backgrounds in math and science instruct more than one group of students.48 This “team teaching which allows for content specialization” is one of the factors resulting in Sojourner Elementary School in Oregon being named a “Star Innovator” School by Intel Foundation in 2008.49

Connections to Professional STEM Community

STEM schools take advantage of connections to the professional STEM community in order to enhance learning opportunities for students and to provide them with examples of real-world applications. The partnerships may range in intensity from rather casual and frequent to very formal and may serve to help “offer students more creative programs, role models, support, and continuity across school years and

---

Examples of potential partner institutions for STEM schools include the following:

- Corporations
- Institutions of higher education
- Regional STEM centers
- Museums

The following graph displays the most frequently occurring STEM school partnerships. Responses are divided according to the school status as either inclusive or selective. In general, partnership types are used approximately equally among school types, although inclusive schools appear to be more likely to use community college partnerships.

**Figure 2.3: Partnerships by School Type**

<table>
<thead>
<tr>
<th>Type of Partner</th>
<th>Percent of Schools</th>
</tr>
</thead>
<tbody>
<tr>
<td>University or 4-year college</td>
<td>41</td>
</tr>
<tr>
<td>Community college</td>
<td>44</td>
</tr>
<tr>
<td>Industry/business</td>
<td>30</td>
</tr>
<tr>
<td>Science center or research lab</td>
<td>37</td>
</tr>
<tr>
<td>Career technical school</td>
<td>33</td>
</tr>
<tr>
<td>Inclusive; n = 71</td>
<td></td>
</tr>
<tr>
<td>Selective; n = 80</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td></td>
</tr>
</tbody>
</table>

Source: SRI International

**Program Implementation**

Program implementation has to do with the “ways in which an innovation or program unfolds in a particular setting” and “includes the ways in which intended program elements function within the context of the resources, setting, structures,
and capacity of a particular site.”

Research indicates that there are three key topics related to successful STEM school implementation: support structures, teacher recruitment and professional development, and assessment practices. These topics are outlined in the table below:

Table 2.1: Elements of Implementation

<table>
<thead>
<tr>
<th>Support Structures</th>
<th>Teacher Recruitment and Professional Development</th>
<th>Assessment Practices</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Academic support structures for students include tutoring, mentoring, clubs and activities, counseling and advising, and scholarship commitments.</td>
<td>• Qualified teachers are essential to STEM school teaching and professional development is necessary to cultivate content knowledge as well as pedagogical knowledge</td>
<td>• Performance-based, formative, and summative assessments allow institutions determine whether the curriculum is having the intended impact on student outcomes</td>
</tr>
</tbody>
</table>

Innovative practices are required in order to recruit adequate numbers of highly qualified teachers in STEM subjects. One such method is to target teachers through nontraditional or alternate teacher certification programs. STEM schools may also wish to consider differentiated pay systems designed to attract the most qualified teachers. These market- and performance-based pay systems can help to address the subject-area shortages in math and science.

*Anecdotal Evidence of STEM School Implementation*

A survey of inclusive STEM schools in Texas reveals that an important factor in their success was the development of a **STEM school blueprint** that guided the planning and implementation process.

An interview with the leadership of Cleveland High School in Washington State, which experienced improvements to its high school after the implementation of a

---


54 Ibid.


56 Ibid, p. 16.

The Carol Martin Academy of Mathematics and Science in Kentucky is ranked in the top five high schools in the United States according to Newsweek’s “America’s Best High Schools 2011” report. Tim Gott, Director of the Academy, describes his experience in starting this successful STEM school. The interview emphasized that a slow implementation process allowed for careful research and planning and that visiting other similar STEM schools played an integral in the formation of the specialized high school.

**Program Sustainability**

Sustaining a STEM program involves several factors including building and maintaining local capacity for continuous improvement to STEM structures. Districts must also ensure the availability of funds for the program beyond the implementation phase. Additionally, ongoing feedback and evaluation is necessary to track, measure, and implement changes to the system including instructional models and professional development for teachers.

STEM schools may wish to assess the success of their programs according to quantitative and qualitative measurements. Standardized tests do not adequately serve this function since the goals of STEM education go beyond preparing students academically. Thus, measurements such as the percentage of students who continue...
on to pursue STEM-related majors at the university level or the application of STEM knowledge to non-STEM related careers may also be a relevant metrics.\textsuperscript{62}

Model STEM schools provide frequent opportunities for \textit{strategic planning}. Illinois Mathematics and Science Academy (IMSA) conducted a strategic planning session in 2006 that included 29 members of the faculty and staff as well as the general community.\textsuperscript{63} The 2007-2012 strategic plan includes the following strategies:\textsuperscript{64}

\begin{itemize}
  \item We will develop the whole person.
  \item We will require students to pursue \textit{personalized plans of study}, based on \textit{integrated learning experiences} and assessed on the basis of individual mastery.
  \item We will expand the development, delivery, support and evaluation of IMSA's products and services grounded in imagination and inquiry.
  \item We will generate scholarship that demonstrates the effectiveness of our practices and transfers knowledge produced by our work.
  \item We will develop innovation and entrepreneurial talent and capacity.
  \item We will diversify our funding to provide reliable and flexible financing
\end{itemize}

Finally, \textit{professional development} is also an important factor in sustaining a cutting-edge STEM program. This issue is discussed in more detail in the next section of this report.


\textsuperscript{63} “Strategic Planning.” Illinois Mathematics and Science Academy. https://www3.imsa.edu/about/strategicplanning

Professional Development Opportunities

This section offers an overview of professional development opportunities for STEM educators.

Guiding Principles of Professional Development Programs

Studies have shown that a majority of elementary teachers do not feel prepared to teach mathematics, demonstrating the need for professional development opportunities in STEM education.65 This professional development is necessary for teachers to develop both content knowledge and pedagogical knowledge as it relates to STEM disciplines.

Short term or “one-shot” programs do not allow teachers the adequate time to acquire and subsequently apply the skills they obtain in professional development programs. Professional development for STEM teachers should persist over an extended period of time and should be both learner-centered and knowledge-centered.66 The following table details elements of an effective STEM professional development program.

Table 3.1 Elements of an Effective STEM Professional Development Program

| ❖ Engaging teachers in practicing concrete tasks related to teaching, assessment, and observation of learning |
| ❖ Drawing upon teachers' questions, inquiry, and experiences |
| ❖ Including time for collaboration, sharing and exchange of ideas and practices |
| ❖ Building on teachers' current work with students |
| ❖ Providing modeling, coaching, and problem-solving around specific areas of practice |

Source: Journal of Technology Studies

The following figure is based on a survey of K-12 educators in southwestern Pennsylvania regarding various aspects of STEM education. Figure 3.1 represents the percentage of teachers expressing interest for professional development in various STEM-related topics. Teachers were most interested in topics focused on career awareness, inquiry based activities, and interdisciplinary activities. This information may be useful when planning professional development programs.

---

Figure 3.1: Teacher Interest in STEM Career Topics for More Effective Preparation of Students\textsuperscript{69}

<table>
<thead>
<tr>
<th>STEM Topic</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Career Awareness</td>
<td>76</td>
</tr>
<tr>
<td>Inquiry Based Activities</td>
<td>72</td>
</tr>
<tr>
<td>Interdisciplinary Activities</td>
<td>64</td>
</tr>
<tr>
<td>Help Collect &amp; Analyze Data</td>
<td>56</td>
</tr>
<tr>
<td>Computer Applications</td>
<td>54</td>
</tr>
<tr>
<td>Energy &amp; Environment</td>
<td>48</td>
</tr>
<tr>
<td>Engineering &amp; Design</td>
<td>38</td>
</tr>
<tr>
<td>Robotics &amp; Computer Science</td>
<td>38</td>
</tr>
<tr>
<td>Biotechnology</td>
<td>32</td>
</tr>
</tbody>
</table>

Source: Carnegie Mellon University and The Intermediate Unit 1 Center for STEM Education

The same survey also questioned teachers’ preferred mode of delivery for these professional development activities with a majority preferring visits and tours or intermediate unit workshops (professional development workshops hosted by the local regional education service agency). This information is displayed graphically in figure 3.2 below.

Figure 3.2: Interest in Career Awareness Professional Development Formats

<table>
<thead>
<tr>
<th>Professional Development Format</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visits &amp; Tours</td>
<td>69</td>
</tr>
<tr>
<td>Intermediate Unit Workshops</td>
<td>69</td>
</tr>
<tr>
<td>Paid &quot;Educator in the Workplace&quot; Activities</td>
<td>66</td>
</tr>
<tr>
<td>University Workshops</td>
<td>58</td>
</tr>
<tr>
<td>Video Conferencing</td>
<td>35</td>
</tr>
</tbody>
</table>

Source: Carnegie Mellon University and The Intermediate Unit 1 Center for STEM Education

Examples of Professional Development Programs

The following provides two examples of well-established professional development programs for K-12 STEM educators.

- **Project Lead the Way (PLTW):** PLTW works with middle schools and high schools to develop coherent STEM education programs.\(^{70}\) PLTW offers teacher training in three phases: readiness training, core training, and ongoing training.\(^{71}\) The readiness training is offered online in preparation for the core training.\(^{72}\) Core training occurs during two-week sessions. These sessions offer models of project- and problem-based STEM courses.\(^{73}\) Finally, ongoing training is primarily offered through the PLTW Virtual Academy.\(^{74}\)

- **National Center for Technology Literacy:** The Museum of Science in Boston offers professional development opportunities for K-12 teachers in engineering and technology. Professional development opportunities include online courses that feature hands-on projects, as well as a workshop “Engineering is Elementary,” specifically designed for elementary school teachers.\(^{75}\) This program has been particularly successful in improving content knowledge and interest in STEM subjects, especially among underrepresented groups such as girls, English language learners, and minority students.\(^{76}\)

- **Battelle for Kids:** Battelle for Kids is a not-for-profit organization created in 2001 with the goal of improving student achievement in Ohio.\(^{77}\) In addition to offering educational services on a broad range of subjects, Battelle also works with the Ohio STEM Learning Network specifically to help launch STEM platform schools, spread STEM initiatives, and to develop sustainable STEM initiatives.\(^{78}\) Although not all of Battelle for Kids’ professional development programs are necessarily focused specifically on STEM education, these programs nevertheless champion many of the best practices detailed earlier in

\(^{70}\) “Who We Are.” Project Lead the Way. http://www.pltw.org/about-us/who-we-are

\(^{71}\) “PLTW Teacher Training.” Project Lead the Way. http://www.pltw.org/educators-administrators/teacher-training

\(^{72}\) “PLTW Teacher Training.” Project Lead the Way. http://www.pltw.org/program-support/teacher-training


\(^{74}\) “PLTW Teacher Training.” Project Lead the Way. http://www.pltw.org/program-support/teacher-training


this report. For example, the professional learning programs are designed to be **ongoing, job-embedded, and hands-on.**

Battelle for Kids currently offers educators several online courses including Formative Instructional Practices, Value-Added Analysis, Goal-Setting, and Strategic Compensation. An illustration of how these courses may contribute to STEM professional development concerns the Strategic Compensation series. This course will allow educators to learn how to implement an effective performance-based pay system which many researchers espouse as an essential strategy for attracting the most talented STEM teachers. In addition to online courses, Battelle for Kids also hosts conferences and offers training workshops and seminars.

Battelle for Kids is working with the Tennessee Department of Education as part of the First to the Top initiative to improve K-12 education. In support of this effort, Battelle for Kids will offer several regional trainings for Tennessee educators including, value-added trainings and formative instructional workshops.

---


Model STEM School Programs

In this final section of the report we profile two selective STEM high schools, one inclusive STEM high school, and one inclusive STEM elementary school. These schools were selected based on their rankings in *Newsweek* as well their identification by other sources as “model” STEM programs.

Illinois Mathematics and Science Academy

Several sources identify the Illinois Mathematics and Science Academy (IMSA) as a model program for STEM Education. Additionally, the Academy won the Intel Foundation’s “Star Innovator” Award in 2009, the highest award offered by the foundation to schools demonstrating excellence in mathematics and science education. The high school is also ranked as one of the top fifty high schools in the United States according to *Newsweek*’s “America’s Best High Schools” report.

Program Characteristics

Founded in 1985, IMSA is a highly selective, residential high school offering specialized mathematics and science education to Illinois students in grades 10 through 12. The Academy declares that its mission is to:

…ignite and nurture creative, ethical scientific minds that advance the human condition, through a system distinguished by profound questions, collaborative relationships, personalized experiential learning, global networking, generative use of technology and pioneering outreach.

The competitive application process includes the submission of SAT scores and high school transcripts. Given that enrollment is open to students throughout the state, students typically live in on-campus residence halls.

---

86 “About IMSA.” Illinois Mathematics and Science Academy. https://www3.imsa.edu/about
**Curriculum**

All of the courses offered at IMSA are taught at the honors level. The IMSA curriculum is built around four core competencies that guide learning opportunities for all students. The following table describes these learning principles:

<table>
<thead>
<tr>
<th>Competency-driven learning experiences</th>
<th>• These experiences allow students to acquire, use, and apply knowledge in solving real world problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inquiry-based learning experiences</td>
<td>• These experiences foster and take advantage of innate curiosity in order to develop analytic thinking, knowledge generation and application, and construction of meaning</td>
</tr>
<tr>
<td>Problems-centered learning experiences</td>
<td>• These experiences allow students to find creative solutions to complex, open-ended problems</td>
</tr>
<tr>
<td>Integrative learning experiences</td>
<td>• These experiences serve to highlight connections within and across subject areas and real-world scenarios</td>
</tr>
</tbody>
</table>

Source: Illinois Mathematics and Science Academy

In addition to traditional core subjects including mathematics, science, English, history and social science, world languages, fine arts, and wellness, students at IMSA have the opportunity to pursue Independent Study, participate in mentorships, and attend interdisciplinary seminars. Students attend four days of structured courses and spend Wednesdays pursuing independent courses of study and research opportunities.

**Extracurricular Programs**

IMSA provides its students with the possibility of participating in many of the clubs and organizations found at typical high schools across the United States. In addition

---

90 FAQ.” Illinois Mathematics and Science Academy. https://www3.imsa.edu/admissions/FAQ
92 Ibid.
to these programs, IMSA also offers its students the opportunity to pursue additional interests outside the standard curriculum. These one-week, optional Intersessions include special math and science topics, liberal arts topics, language courses, and various field trips.\textsuperscript{95} The following table offers a few examples of full- and part-time topics available in 2011, but does not represent an exhaustive list of programs.\textsuperscript{96}

### Table 4.2: Selected IMSA Intersession Offerings 2011

<table>
<thead>
<tr>
<th>Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic Open Water Scuba Certification</td>
</tr>
<tr>
<td>Campus Makeover: Redesigning a Sustainable IMSA Campus</td>
</tr>
<tr>
<td>Chinese Youth and Pop Culture</td>
</tr>
<tr>
<td>Cultural Competency: Understanding Others</td>
</tr>
<tr>
<td>Hands of Conversation and More</td>
</tr>
<tr>
<td>Hands-on Engineering: Designing and Building a Robot for FIRST</td>
</tr>
<tr>
<td>IMSA-PTHS Student Exchange (Russia)</td>
</tr>
<tr>
<td>Learning Leadership</td>
</tr>
<tr>
<td>Matsubayashi-Ryu Karate Training Camp</td>
</tr>
<tr>
<td>Microcontrollers: Electronic Project</td>
</tr>
<tr>
<td>Practical Explorations in Emergency Medicine</td>
</tr>
<tr>
<td>So You Wanna be a Doctor</td>
</tr>
<tr>
<td>Studio: Architecture and Design</td>
</tr>
<tr>
<td>Beginning European Knitting</td>
</tr>
<tr>
<td>Economics, Politics, the Media and Your Future</td>
</tr>
<tr>
<td>Nuclear Weapons and WMD</td>
</tr>
<tr>
<td>Asian Antagonisms: Current Diplomatic Confrontations in Asia</td>
</tr>
<tr>
<td>Creating Social Applications on Facebook</td>
</tr>
<tr>
<td>Energy Center Project</td>
</tr>
<tr>
<td>Stem Cell Biology and Technology: From Patients to Patents</td>
</tr>
</tbody>
</table>

### Outreach

IMSA is very active in state outreach programs for elementary and secondary school students as well as in professional development for teachers. Bayer Corporation’s award winning “Making Science Make Sense” (MSMS) program recognizes the IMSA FUSION \textsuperscript{97} (formerly known as IMSA Excellence 2000+ (E2K+)) program as one of its K-12 Best Practice Programs for developing science literacy in underserved populations. The program includes weekly IMSA FUSION sessions offering hands-on experiences for students in grades 4 through 8 at locations throughout the state, as

\textsuperscript{95} “Intersession 2012.” Illinois Mathematics and Science Academy.
  https://www3.imsa.edu/learning/Intersession%20

\textsuperscript{96} “Intersession 2011.” Illinois Mathematics and Science Academy.

well as professional development opportunities for teachers. Professional development includes the following components:

- All site staff is required to participate in a one-day Pedagogy, Orientation and Planning (POP) Workshop generally held during June or July. At this session, program changes and updates are introduced, new site staff is oriented to IMSA FUSION by veteran teachers and all are given the opportunity to begin planning for the coming year. The POP Workshops are held at IMSA and at regional locations.

- Each Unit Workshop requires two full days of active participation. Curriculum books and unit materials are distributed only to participants attending these professional development sessions. The Unit Workshops are held at IMSA and at regional locations.

- Culminating Webinars are held after school hours on multiple dates in May and June. Each Webinar lasts from two to three hours, and is conducted via distance learning technology. The local IMSA FUSION team (teachers and coordinator) at each participating site prepares a short PowerPoint presentation for the event. Members of the IMSA FUSION site team may participate in a Culminating Webinar from any location of the participants’ choosing.

In addition, Supplemental-Unit Workshops that help address problem-solving approaches and Administrator Information Sessions that provide principals and administrators with the opportunity to network and receive more information about IMSA FUSION are provided. All professional development activities earn Continuing Professional Development Units due to the IMSA’s relationship with the Illinois State Board of Education.

As a result of the program, participating students demonstrated a change in academic skills related to problem-solving and also demonstrated an increased interest in science which lasted throughout high school.

**Thomas Jefferson High School for Science and Technology**

Several sources identify Thomas Jefferson High School for Science and Technology (TJHSST) as a model program for STEM Education. Additionally, the high school won the Intel Foundation’s “School of Distinction” award for science excellence in 2010.

---


99 Ibid.

100 Ibid.


Program Characteristics

Founded in 1985, TJHSST is a highly selective high school offering specialized math, science, and technology education to Virginia students in grades 9 through 12.\textsuperscript{104} The competitive application process includes an examination of students GPAs (which cannot be lower than 3.0 on a 4.0 scale) and entrance exams test scores.\textsuperscript{105} According to TJHSST, its mission is to:\textsuperscript{106}

\begin{quote}
...provide students a challenging learning environment focused on math, science, and technology, to inspire joy at the prospect of discovery, and to foster a culture of innovation based on ethical behavior and the shared interests of humanity.
\end{quote}

Curriculum

In addition to the emphasis on science, math, and technology, the TJHSST core curriculum includes a Freshman IBET (Integrated Biology, English, and Technology) course, computer science, humanities, foreign languages, fine arts, and physical education.\textsuperscript{107} Seniors are required to complete a technology laboratory project in order to graduate.\textsuperscript{108} TJHSST approaches learning in an interdisciplinary manner and all courses are guided by the following six learning methodologies:\textsuperscript{109}

- Acquiring powerful communication skills
- Developing collaborative skills
- Thinking and working in the context of systems
- Working with real projects and problems
- Managing change
- Developing and ethical culture

Extracurricular Programs

One of the eight periods at TJHSST each day is devoted to student activities and clubs. The activities offered at TJHSST reflect traditional clubs and sports as well as programs unique to TJHSST given its access to a wealth of technological tools. There are approximately 165 clubs and 25 varsity sports.\textsuperscript{110} Students can choose from academic, career, cultural, faith, fine arts, forensic, games, honor society, language,

\begin{footnotesize}
\textsuperscript{104} “Admissions.” Thomas Jefferson High School for Science and Technology. http://www.tjhsst.edu/about/tj/admissions/about_us.html
\textsuperscript{108} Ibid.
\textsuperscript{109} Ibid.
\end{footnotesize}
literary, science/math, service, social sciences, sports, technology, and visual arts based activities.\textsuperscript{111}

Outreach

TJHSST plays an active role in \textbf{community outreach programs} aimed at spreading and improving STEM education. A few examples of these programs are highlighted below:\textsuperscript{112}

- Collaboration with local universities to develop opportunities for students and staff
- Summer Technology Programs offered to all students
- Annual technology conference for educators
- Peer mentoring and tutoring for students at local elementary and middle schools

High Tech High

Several sources identify High Tech High as a model program for STEM Education.\textsuperscript{113} The high school was founded in 2000 by a group of high-tech industry professionals seeking to cultivate local STEM talent.\textsuperscript{114} Originally established as a single high school, High Tech High now oversees eleven schools in San Diego including two elementary schools, four middle schools, and five high schools.\textsuperscript{115}

Program Characteristics

High Tech High is an \textbf{inclusive school system} that selects students based on a random lottery system.\textsuperscript{116} The high tech focus of the high school is evident in its \textbf{architectural design}, which resembles a high-performance workspace more than a high school. Architectural features include high ceilings, an abundance of windows, conference rooms, and various textural elements.\textsuperscript{117} High Tech High’s mission “is to develop and support innovative public schools where all students develop the academic, workplace, and citizenship skills for postsecondary success.”\textsuperscript{118} In support

\textsuperscript{111} Ibid.
\textsuperscript{117} “HTH Facilities.” High Tech High. http://www.hightechhigh.org/about/facilities.php
\textsuperscript{118} “About High Tech High.” High Tech High. http://www.hightechhigh.org/about/
of this mission, the high school is organized around the following four design principles:\textsuperscript{119}

Table 4.3: High Tech High Design Principles

<table>
<thead>
<tr>
<th>Principle</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Personalization</strong></td>
<td>• Students receive individualized attention from staff for academic planning and personal needs and are also encouraged to follow personal interests through independent projects.</td>
</tr>
<tr>
<td><strong>Adult World Connection</strong></td>
<td>• Students are encouraged to engage in real world activities outside the traditional classroom. These activities include internships, community service, or shadowing industry professionals.</td>
</tr>
<tr>
<td><strong>Common Intellectual Mission</strong></td>
<td>• All students are held to the same rigorous academic standards and there is no &quot;tracking&quot; at High Tech High. Course materials are integrated across subject areas.</td>
</tr>
<tr>
<td><strong>Teacher as Designer</strong></td>
<td>• High Tech High fosters interdisciplinary teaching by allowing for team teaching, common planning time, project-based learning, and work-based learning.</td>
</tr>
</tbody>
</table>

Source: High Tech High

One-third of graduates at High Tech High are \textbf{first-generation college students} and outperform their peers in California both test scores and in the number of advanced courses taken.\textsuperscript{120} In order to target underserved student populations, High Tech High employs innovative \textbf{recruiting techniques} which include working with the African American church community and low-income youth programs.\textsuperscript{121}

\textbf{Curriculum}

High Tech High offers its students an integrated curriculum that explores themes cutting across several subject areas and incorporates various hands-on projects. **Assessment is typically performance-based** rather than based on standardized testing methods.\textsuperscript{122} Furthermore, High Tech also places an emphasis on liberal arts training.

High Tech High works with the professional STEM community in order to increase learning opportunities for its students. **Academic internships** are a requirement for graduation and students may work at local businesses or research organizations.\(^{123}\)

**Extracurricular Programs/Outreach**

High Tech High encourages visits from other education professionals seeking to learn about STEM school implementation models.\(^{124}\) Examples of these professional development opportunities include:\(^{125}\)

- Teacher residencies and institutes at High Tech High
- Teacher ambassador programs
- On-site technical assistance
- A graduate school of education offering masters degrees in teacher leadership and school leadership

The topics covered during professional development opportunities are quite extensive and include guides for the following:\(^{126}\)

- Project-based learning
- Curriculum integration
- Internship program development
- Teaching to diverse learners
- Student advisory
- College advising
- Facilities development
- Technology infrastructure and policies
- Management

**Oakcliff Traditional Theme School**

A majority of STEM-focused schools serve high school students. However, Oakcliff Traditional Theme School in Georgia provides one example of a STEM-focused elementary school. Several sources identify Oakcliff as a model program for STEM Education.\(^{127}\) Additionally, the elementary school won the Intel Foundation’s “School of Distinction” award for science excellence in 2009.\(^{128}\)


\(^{126}\) Ibid.


Program Characteristics

Oakcliff is an inclusive elementary school serving students in pre-kindergarten through grade 5. Oakcliff Traditional Theme School is “a diverse learning community, is dedicated to empowering students to become productive members of society and life-long learners in a safe, challenging and creative environment.”

Curriculum

Students at Oakcliff are held to high academic standards under the belief that higher expectations lead to higher academic performance. The curriculum includes the following features:

- Concentrated instruction in core subjects
- Emphasis on classical literature
- Spanish instruction
- Science laboratory
- Accelerated Reader Program
- Accelerated Math Program
- Computer Lab, Compass Learning, Hands-on projects and activities
- School wide Tutorial Program
- English services for non-speakers
- A wide variety of school clubs and organizations
- Commitment to protect teaching time for teachers and learning time for students
- Academic Counseling
- Parenting Center/Parenting Library

Extracurricular Programs

The U.S. Department of Education has recognized Oakcliff’s Small Fry to Go (SFtG) program as the number one afterschool science program in the United States. This program provides instruction beyond the traditional school day to all interested elementary students throughout the year. The project follows the growth of rainbow trout, starting from their infancy as eggs to their release in a local river.

---

Outreach

Students at Oakcliff are encouraged to be active in the community. They are encouraged to engage in service learning projects, school beautification, peer tutoring, scouting, mediation, and academic bowls.134

---

Project Evaluation Form

Hanover Research is committed to providing a work product that meets or exceeds member expectations. In keeping with that goal, we would like to hear your opinions regarding our reports. Feedback is critically important and serves as the strongest mechanism by which we tailor our research to your organization. When you have had a chance to evaluate this report, please take a moment to fill out the following questionnaire.


Caveat

The publisher and authors have used their best efforts in preparing this brief. The publisher and authors make no representations or warranties with respect to the accuracy or completeness of the contents of this brief and specifically disclaim any implied warranties of fitness for a particular purpose. There are no warranties which extend beyond the descriptions contained in this paragraph. No warranty may be created or extended by representatives of Hanover Research or its marketing materials. The accuracy and completeness of the information provided herein and the opinions stated herein are not guaranteed or warranted to produce any particular results, and the advice and strategies contained herein may not be suitable for every member. Neither the publisher nor the authors shall be liable for any loss of profit or any other commercial damages, including but not limited to special, incidental, consequential, or other damages. Moreover, Hanover Research is not engaged in rendering legal, accounting, or other professional services. Members requiring such services are advised to consult an appropriate professional.