Developing Middle School STEM Programs

District Leadership Forum

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1) Executive Overview

Key Observations

Profiled districts offer middle school STEM programs to students primarily through integrated curricula. Program coordinators at **Institution B**, a nonprofit that manages STEM programs for local districts, explain that STEM programs not incorporated into the general curriculum often receive less financial and/or administrative support compared to standardized-tested, core subjects (e.g., language arts, math). This often puts STEM programs at risk of cancellation or subject to ineffective teaching practices. Contacts at **District C**, **School D**, and **School A** also emphasize the importance of integrating STEM into the general curriculum, especially as a pedagogical tool for increasing student knowledge retention.

Contacts at profiled districts emphasize an interdisciplinary approach to middle school STEM programing. All contacts from profiled STEM programs emphasize the importance of an interdisciplinary curriculum to create effective STEM programs. An interdisciplinary approach facilitates the development of students' critical-thinking skills, which are necessary to perform well on standardized tests. Contacts at **School D** note that implementation of an interdisciplinary curriculum is more attainable and effective in middle school than in a high school curriculum. Contacts at **School A** confirm this, noting that interdisciplinary programs become more difficult in high school as students often specialize in certain disciplines or academic tracks.

STEM programs should encompass learning strategies that focus on the development of critical-thinking skills in middle school students. Contacts emphasize the incorporation of real-world, problem-solving skills into both the general curriculum and STEM-related activities. Contacts at **Institution B** explain that problem-solution focused learning gives students an innovative method for learning content that increases student interest in STEM and school more generally. Contacts emphasize connecting activities and curricula to issues outside the classroom so that students feel empowered to solve real-world problems.

Effective STEM programs require initial and ongoing support from administrators and teachers to be successful. Without supportive administrators, even the most qualified teachers will struggle with sustaining an impactful STEM program. For example, weak administrative support led to stagnation in the STEM programming at **School D**. However, contacts note that a more supportive, successor administration fostered collaboration and effective growth. In addition, contacts at **Institution B** explain that a supportive administration will not be able to develop effective STEM programming without qualified and engaged teachers. To address this, contacts at **District C** utilize a large professional development budget to foster teacher growth and support for STEM programs. The STEM coordinator utilizes a centralized professional development process that gives teachers who do not feel comfortable with STEM topics the opportunity to grow more comfortable in the discipline.

2) Program Structure

Integrated Program Design

All Profiled Programs Integrate Interdisciplinary STEM Learning Into School Curriculum

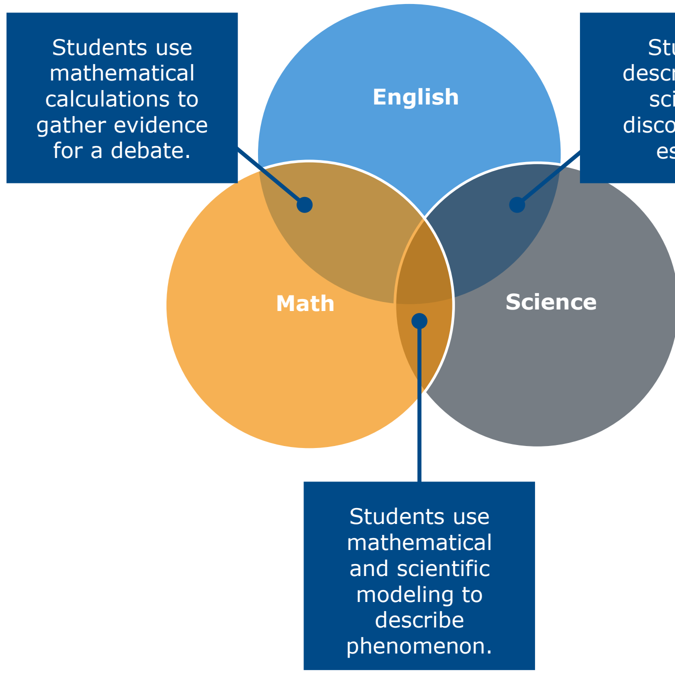
All profiled STEM programs include interdisciplinary qualities and are integrated into the general curriculum. Integration of STEM programming is the inclusion of STEM content and learning in all of the standard-based disciplines (i.e., reading, history) as a foundation for understanding and using STEM concepts.

STEM Programs at Profiled Schools and Districts

School Name	Program Description
School A	Administrators at **School A** offer integrated and interdisciplinary programming to all students. It is the only profiled program to offer STEM electives in addition to the STEM programming embedded into the general education curriculum. Students must complete one of these elective courses as a middle school graduation requirement.
Institution B	The **Institution B** provides STEM programming consultancy services to area schools. Institution B is involved primarily in program planning, rather than program implementation. The network has successfully partnered with over 200 community partners to extend and enhance local STEM learning.
District C	**District C** offers an integrated and interdisciplinary STEM program to all students. Students also have access to STEM clubs (e.g., robotics) and makerspaces in each school. Qualified students have the opportunity to opt into a more research-intensive track of STEM programming.
School D	**School D** offers an integrated and interdisciplinary focused STEM program to select students. Of the profiled STEM programs, it is the only program to have entry requirements.

All contacts note that STEM programs should be integrated into the regular curricula to increase the impact programming has on student knowledge retention. At **Institution B**, contacts explain that students are less likely to retain information taught in isolation, without connections made to other disciplines or topics. However, if students approach a topic in an integrated manner, they can appreciate the topic from several points of view (e.g., learning about physics from a historical perspective). Similarly, contacts at **District C** and **School D** emphasize that STEM programs should not create a division between STEM-proper courses and other courses.

Comparing Integrated and Interdisciplinary STEM Programming



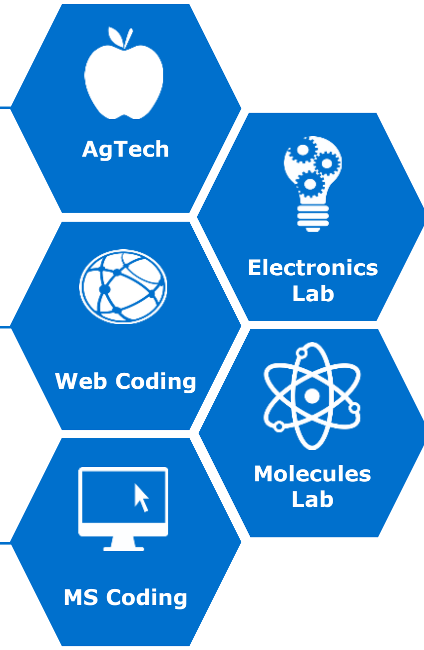
Elective Options

STEM Electives Provide Students with Specialized Knowledge to Complement the General Curriculum

School A's STEM program utilizes STEM electives to complement other interdisciplinary STEM programming. The electives occur after regular school hours and do not replace a science credit, as the course is meant to complement general learning. Students must complete a STEM elective as a graduation requirement. As a graduation requirement, the elective becomes integral to students' academic progression. This can avoid complications with electives receiving less support and attention than core subjects.

Contacts also emphasize offering electives that cover a range of STEM topics, so students may choose programs that most interest them. To further allow students to explore STEM interests, administrators at School A offer math, technology, and robotics clubs in addition to the STEM electives and integrated STEM curriculum to middle school students.

Examples of *School A's* Middle-Level STEM Elective Options



AgTech: In this elective, students will grow crops in self-sustained 3D-printed pods. Students will code an app to monitor their crops' health and to communicate with other students what care needs to be given and what chores have been completed.

Web Coding: Students use a programming language to learn control flow, object-oriented principles, and debugging techniques. By the program's end, students are able to implement their own game and deploy it to the web.

MS Coding: Students learn a variety of programming languages to get a solid understanding of computer science concepts. Students then design and implement their own web or mobile app utilizing real-world programming processes and tools.

Electronics Lab: Students learn about circuits, programming, and debugging techniques through the Arduino interface, a computer hardware and software interface program. By the end, students are able to combine their knowledge of physical technical components with programming skills.

Molecules Lab: This elective challenges students to come up with novel ratios of metallic alloys to attempt to split water molecules. Students present their work at a local university conference at the end of the spring semester.

Offer Advanced STEM Programing to Select Students Concurrently with General Programing

Certain students demonstrate advanced proficiency in STEM disciplines, as well as expressed interest in the field. To cater to these students, some profiled districts offer more advanced STEM programming in addition to the general, integrated-STEM curriculum. For example, while all students in **District C** receive interdisciplinary STEM education through the general curriculum, district administrators also offer an additional, research-intensive STEM program based on high school requirements, to some middle school students. The program culminates in a research project during eighth grade that students present at a symposium. This concurrent program allows students more academically inclined toward STEM to advance their skills and knowledge in STEM-related topics.

Administrators at **School D** also offer STEM programming to a select group of students each year. Students with a GPA of 3.25 or above, a reading level in the 60th percentile, and an interest in STEM can apply. Contacts explain that about one sixth of applicants (i.e., 50 students) receive placement in the program. The selective nature of the program aims to sustain rigor and content complexity for students. Contacts explain that previously, students involved in the program without the necessary academic qualifications would struggle with reading content and discussions. This impacted the entire classroom, as some students were unable to progress adequately through the content or participate meaningfully in class discussions, ultimately making the program less impactful.

Qualifications for Participation in Selective STEM Programming at *School D*

Reading Competency

Students must have a reading level in the 60th percentile.

Interest in STEM

Students show a genuine interest in STEM.

GPA Requirement

Students have and maintain a 3.25 GPA.

2) Program Implementation and Teaching Strategies

Program Implementation

Motivations for STEM Program Development Vary from Administration Changes to School Choice

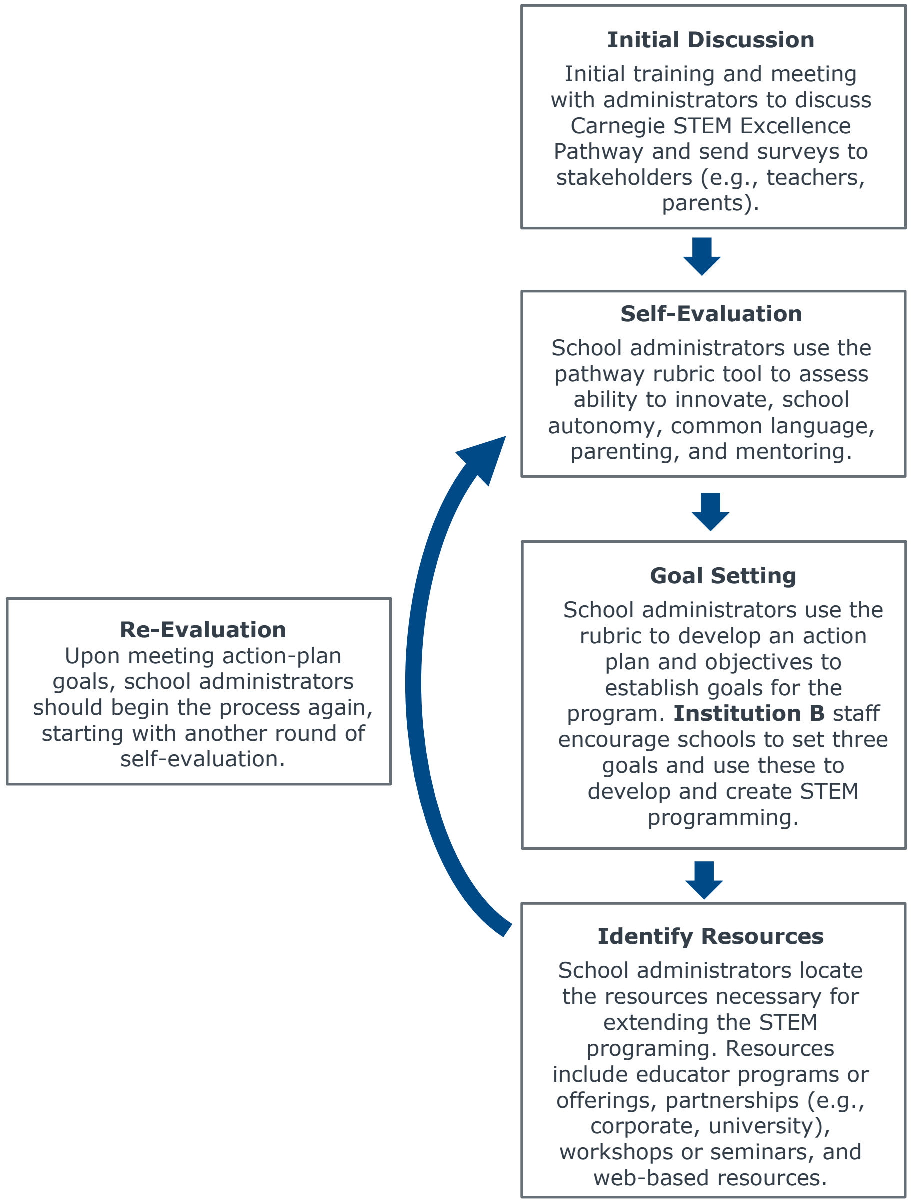
Contacts at **School A** and **School D** explain that buy-in from leadership, stemming from administrative change, led to more substantial STEM programs. While the program existed prior to changes in administration, contacts at School D explain that a new superintendent's support for the existing program directed funding and renewed interest towards enhancing STEM learning. Similarly at School A, the STEM program expanded as a result of the new head of curriculum, who hoped to foster more robust STEM learning in the school.

Motivations differ in **Institution A**'s area of work, where school choice policies greatly influence program development. Contacts at **Institution B** explain that local schools are part of a school choice policy. This policy requires public funds for individual students to be directed to the school the child attends. This incentivizes schools to offer innovative and unique programs, like STEM, to attract students and their parents.

Conduct Needs Assessment Prior to Developing STEM Curriculum

Contacts at **Institution B** note that the organization primarily facilitates the implementation process of STEM programs in local schools. When school administrators express interest in beginning a STEM program, school administrators first attend a training to learn to effectively complete a STEM programming-related needs assessment for the school. The Carnegie STEM Excellence Pathway rubric provides the basis for the needs assessment, which assists administrators in developing an action plan to address gaps in STEM programming. The Carnegie STEM Excellence Pathway rubric also emphasizes the regular reassessment of programs to help schools progress to higher levels of STEM education excellence. The rubric helps encourage school leaders to continue to assess the status of programs and develop new goals once the action plan meets its initial goals.

Carnegie STEM Excellence Pathway Process for the Development of STEM Programming[1]



Use Rubrics to Measure Program Progression

Contacts at **Institution B** recommend using the Carnegie STEM Excellence Pathway, the rubric used during the initial needs assessment process, to measure success. Revisiting the rubric encourages school administrators to continuously build upon new practices and assess the progress and success of the STEM program. Contacts at Institution B note that rubrics used in initial STEM-program development also prove to be useful assessment tools. Because schools develop programs using the rubric metrics, comparisons and assessments of progress become more effective. For example, using a rubric template, school administrators would select a goal, outline the process for achieving the goal, and then use the rubric to compare execution to the original rubric criteria. Similarly, at **School D**, STEM program coordinators develop curriculum rubrics that dictate yearly standards for programming. Contacts

1) Planning for STEM Excellence, Carnegie STEM Excellence Pathway, Carnegie Science Center, 2015, http://www.carnegiesciencecenter.org/csc_content/stemcenter/pdf/pathway_1_pager_and_rubric_combo_2015.pdf

explain that the thematic and interdisciplinary nature of STEM programming at School D impacts the rubric.

Excerpt from Carnegie STEM Excellence Pathway Rubric[2]

Administrators from individual schools work with **Institution B** coordinators to document the current status of STEM programming in their schools. This information is based on conversations between other stakeholders, such as teachers and parents.

	Pre-Emerging	Emerging	Progressing	Advancing	Leading
Curriculum					
Diversity and Breadth of STEM Curriculum Offering	There is no current action in this area.	STEM course content is available in all core science areas (life, earth, and physical science) and in computer/tech-nology literacy. STEM course content is aligned with state standards.	STEM course content is available in all core science areas and in basic computer programming. A second year of coursework is available in at least one science or technology area. Courses are designed to more rigorous standards such as Next Generation Science Standards.	Meets all previous criteria and offers post-secondary or AP level in at least one area. At least one course is offered in a broader range of STEM areas such as engineering, computer programming, technical design, and/or computer-aided machining.	STEM courses are available in all core science areas, including calculus at the post-secondary or AP level. A broader range of STEM coursework is readily available. Capstone courses incorporate interdisciplinary approaches (e.g., environmental science, public health).
Mark district's current status overall					
Notes on variations in status within the district					
Notes on evidence for current status					

Include Relevant Stakeholders in Program Development to Ensure Buy-In

Contacts at **Institution B** and **District C** emphasize the necessity of including all relevant stakeholders in the initial STEM-programming implementation process. During the needs assessment portion of Institution B's implementation process, school administrators partnering with Institution B share a survey with teachers and parents. This gives Institution B and current administrators a well-rounded assessment of the current status of STEM learning at the school.

Similarly, administrators at District C used focus groups to involve teachers and parents early in program planning discussions. Contacts emphasize establishing separate focus groups for individual groups of stakeholders (e.g., middle school administrators, high school administrators, teachers, parents) to give all involved an

2) Planning for STEM Excellence, 2015

equal position in the discussions. During these initial focus groups, teachers, parents, and administrators can express feelings related to changes in STEM programming, such as concerns or ideas for future programming. Focus groups for the teachers specifically allow the STEM coordinator to lay out specific goals and expectations for the teachers moving forward. Contacts explain that this strategy allows teachers to feel engaged in the decision-making process and allows them to express frustration, resentment, or excitement in a controlled setting.

Stakeholders Involved in STEM Program Focus Groups

Administrators

Administrators understand and report a high-level description of goals and strategic plans. The focus groups allow STEM coordinators to bring administrator attention to the concerns of other parties.

Teachers

Teachers typically face the most impact when faced with changing curricula or standards. Focus groups allow teachers to have a time of dissent, which often manifests into constructive conversations around concerns and goals.

Parents

Contacts emphasize including parents in initial discussions of STEM programming. This allows parents to gain constructive and helpful information early in the process to effectively set expectations.

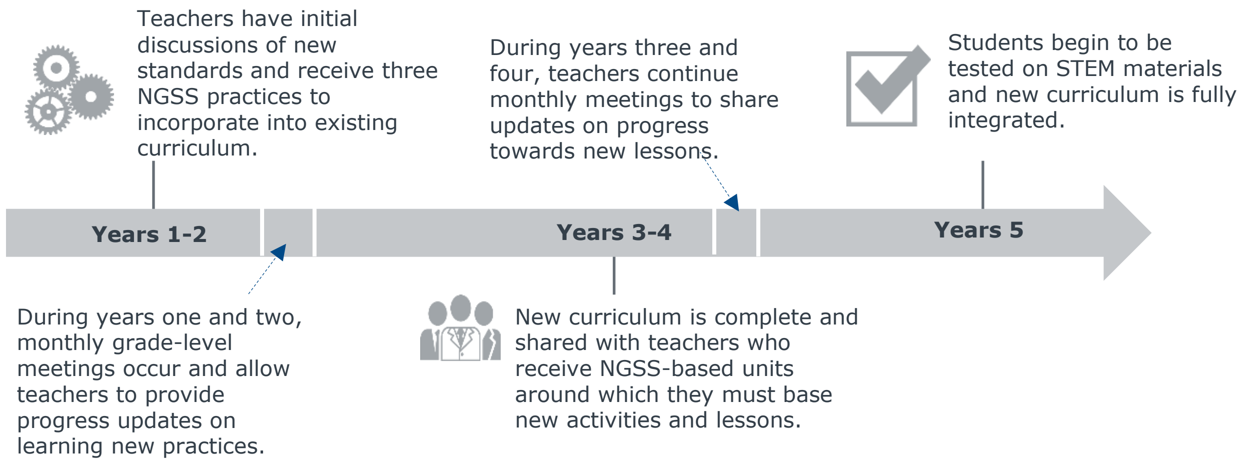
Provide Teachers with Ample Time to Plan and Prepare for New STEM Curricula

Contacts at **School A** and **District C** emphasize the importance of teacher preparedness when developing a new STEM curriculum. Rather than requiring teachers to immediately adopt new standards, administrators should give teachers time to learn the new material. For example, at School A, teachers prepared for STEM teaching using topics they already understood (e.g., weather phenomena) and then gradually moved towards more complex topics (e.g., coding). This fosters a comfort level among teachers, which leads to support for integrated and interdisciplinary curricula.

In District C, STEM coordinators worked with teachers to introduce standards from the Next Generation Science Standards (NGSS), a set of standards developed by states and other organizations such as the National Research Council, into the current program before making any changes to the curriculum.[3] Contacts explain that using a five-year action plan specific to developing a STEM program allowed the school to look towards the future while engaging teachers in the new curricula through consistent STEM-based professional development.

3) FAQS, *Next Generation Science Standards*. No date, https://www.nextgenscience.org/

Sample STEM Teacher Education Process



Teaching Strategies

Use Gamification to Increase Student Interest in STEM Topics

Contacts at **School A** emphasize the incorporation of aspects of game playing into STEM curriculum. The gamification of STEM programs offers an opportunity to engage students while indirectly introducing them to STEM concepts. The incorporation of game playing into classes provides an engaging way for students to apply problem-solving skills to issues affecting their day-to-day life.[4] For example, one teacher uses an activity where teams of students must work together to complete tasks or answer questions before they are able to enter the classroom. Contacts explain that the tasks and questions encourage innovative thinking, problem-solving, and collaboration.

Gamification also increases student engagement in the classroom, which is especially important for middle school students. Contacts explain that developmentally, middle school students strive for decision-making power, while maintaining a sense of enjoyment from play. Using games and play to increase engagement gives educators a better connection with students so that they trust teachers to share their perspective and opinions on learning styles.[5]

Active Learning Activities Assist in Knowledge Retention and Application

Contacts at **District C** and **School D** emphasize the importance of students' active participation in learning activities during STEM programming. Contacts note that teachers need to teach outside of textbooks and state standards to effectively convey STEM concepts. At School D, teachers set the expectation directly with students that new activities may or may not be successful learning opportunities. Contacts explain that students appreciate the honesty, and teachers use challenges with curriculum implementation (e.g., activities not going well, technology malfunctioning) as teaching moments to develop students' abilities to define and solve problems, a concept included in NGSS standards.

Similarly at District C, STEM instruction is based around exploration of real life rather than memorization. This style of instruction, emphasized by NGSS, provides students

4) *Wendy Hsin-Yuan Huang, Soman, Dilip, A Practitioner's Guide to Gamification of Education,* Rotman School of Management, University of Toronto, 10 December 2013, 15.
5) Ibid, 15.

with opportunities to actively apply STEM concepts through the learning process.[6] To ease the shift towards this style of instruction, contacts explain that teachers receive curriculum guides at the beginning of each year. The guides cover this explorative, real-life style of instruction and provide teachers with high-level implementation discussions. For example, the phenomenon of water appearing on the side of a bottle of soda could prompt a lesson on condensation and states of matter.

6) Using Phenomena in NGSS-Designed Lessons and Units, *STEM Teaching Tools*, No Date, http://stemteachingtools.org/brief/42

3) Program Standards and Assessment

Program Standards

State and Internally-Developed Standards Serve as the Basis of Profiled STEM Programs

Administrators at three of four profiled schools and districts use state and internal standards as tools for constructing STEM curricula. Contacts at **Institution B** do not focus on one set of standards, as the organization works with many different local schools. However, a local district created STEM learning modules based on the NGSS. Contacts at all other profiled schools and districts also note the use of NGSS standards in the development of middle school STEM programs.

In addition to NGSS, contacts at **School A** explain that as an independent school, many of the STEM standards were developed internally, but administrators also use Common Core standards. Contacts at **School D** use the Common Core and state educational standards to serve as the foundation of STEM programming.

Sample NGSS Standards for Middle School Natural Selection and Adaptations[7]

NGSS explicitly incorporates critical thinking and communication skills into content learning standards. The practices encourage development of skills necessary for postsecondary success. For example, MS-LS4-1 encourages students to discuss differences and explore patterns in the structure of organisms.

Middle School Natural Selection and Adaptations Standards ***Students who demonstrate understanding can:***
MS-LS4-1. Analyze and interpret data for patterns in the fossil record that document the existence, diversity, extinction, and change of life forms throughout the history of life on Earth under the assumption that natural laws operate today as in the past. [Clarification Statement: Emphasis is on finding patterns of changes in the level of complexity of anatomical structures in organisms and the chronological order of fossil appearance in the rock layers.] [Assessment Boundary: Assessment does not include the names of individual species or geological eras in the fossil record.]
MS-LS4-2. Apply scientific ideas to construct an explanation for the anatomical similarities and differences among modern organisms and between modern and fossil organisms to infer evolutionary relationships. [Clarification Statement: Emphasis is on explanations of the evolutionary relationships among organisms in terms of similarity or differences of the gross appearance of anatomical structures.]
MS-LS4-3. Analyze displays of pictorial data to compare patterns of similarities in the embryological development across multiple species to identify relationships not evident in the fully formed anatomy. [Clarification Statement: Emphasis is on inferring general patterns of relatedness among embryos of different organisms by comparing the macroscopic appearance of diagrams or pictures.] [Assessment Boundary: Assessment of comparisons is limited to gross appearance of anatomical structures in embryological development.]
MS-LS4-4. Construct an explanation based on evidence that describes how genetic variations of traits in a population increase some individuals' probability of surviving and reproducing in a specific environment. [Clarification Statement: Emphasis is on using simple probability statements and proportional reasoning to construct explanations.]
MS-LS4-6. Use mathematical representations to support explanations of how natural selection may lead to increases and decreases of specific traits in populations over time. [Clarification Statement: Emphasis is on using mathematical models, probability statements, and proportional reasoning to support explanations of trends in changes to populations over time.]

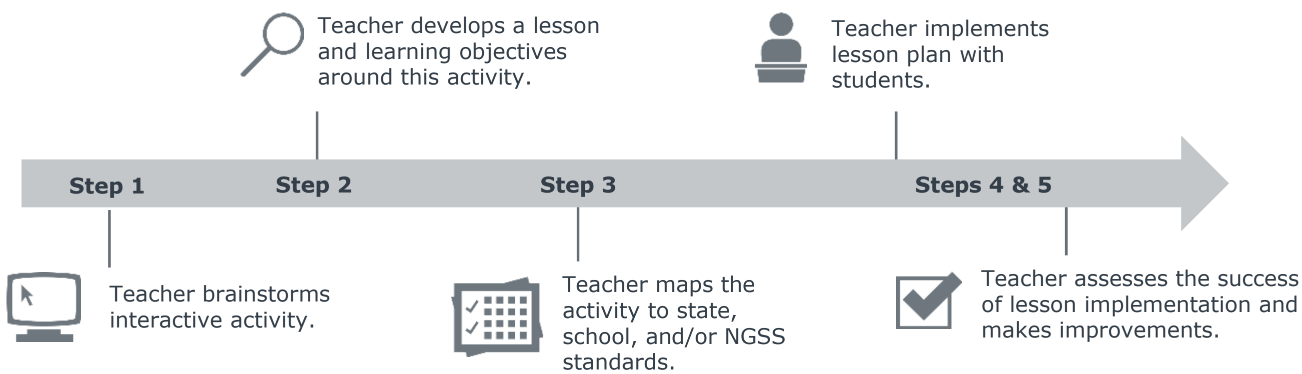
7) Topic Arrangements of the Next Generation Science Standards, *NGSS,* September 2017

Avoid Relying on State Standards When Developing STEM Programs

Contacts at **School D** explain that beholding the success of a STEM program to meeting certain standards can compromise a teacher's ability to innovate in the classroom. When STEM programs focus exclusively on meeting external standards, the activities and projects used in the classroom can lack the engaging characteristics associated with STEM programs.

To address this, contacts at School D explain that teachers should develop activities or projects first and then map those activities back to relevant standards. For example, a teacher might develop an activity that asks students to compare and contrast chocolate that has been melted, broken, or otherwise combined. Using this activity, teachers could connect the different characteristics of the chocolate to parallel types and forms of rocks (i.e., standard MS-ESS2-3).

Sample Lesson Planning Process for Meeting State Standards at *School D*



Program Assessment

Profiled STEM Programs Rely on Standards Fulfillment and Qualitative Surveys to Assess Program Success

Contacts from all profiled STEM programs explain that administrators base assessment on meeting state standards and other curriculum-based standards (e.g., NGSS). School administrators also use qualitative and anecdotal insights to assess program success. Contacts at **School A** and **School D** both note that qualitative insights into student satisfaction and critical-thinking skills serve as stronger measures of STEM programming compared to standard-based, quantitative data. Contacts explain that other than standardized testing scores, generating quantitative data that describes program success is difficult and often does not reveal helpful insights. This is due to the differences in test-taking skills and learning styles among students. Additionally, high aggregate scores do not reveal insights into which lessons or activities are successful in the classroom. Administrators at **District C**, however, do use some quantitative data through surveys that assess student satisfaction in STEM programs. Contacts also emphasize an administrative and district focus on test scores as a measure of success.

Additionally, contacts at School A, School D, and District C explicitly note that they attempt to follow the progress of students through college, recording where students attend, their selected majors, and success. Collecting information around students' success in college is an attempt to understand non-measureable skills, such as critical thinking and problem solving. Contacts explain that these skills, often developed through STEM programming, typically impact the future success of students and highlight the importance of STEM learning. However, contacts do recognize and note that these measures are subjective and do not imply causation that STEM programming leads to student success.

Combine Strategies to Assess Effectively Student Learning in STEM Programming

The measurement of student learning is vital to assessing the effectiveness of STEM programming. The National Research Council (NRC), a contributing developer of NGSS, published a book with useful guidelines for purposefully and successfully assessing student learning in STEM programs. The guide encourages teachers to use a combination of assessment methods and tools. Specifically, the guide encourages the use of both formative and summative assessment methods to assess student performance. The former is defined as student or teacher activities that provide information that can be used to influence learning or instruction.[8] The latter is defined as cumulative assessments that measure what a student has learned.[9] Of profiled institutions, **School A** serves as an example of formative assessment practices as students in required elective courses receive grades throughout the semester on processes and effort, rather than tests or assignments. In contrast, in **District C**, summative assessment is standard practice and students receive grades and focus on achievement on tests (e.g., AP exams).

Because student assessment should influence learning and instruction, varying methods are vital to measuring learning, instruction, and progress. Research explains that there is no single assessment comprehensive enough to fully measure student progress.[10] Therefore, teachers and school administrators need to develop and utilize assessment measures that comprehensively look at student learning. This occurs through the combination of different methods that reveal insight into the every dimension of knowledge (e.g., content, processes).

Overview of Differences between Formative and Summative Style Assessment[11]

	Purpose	Roles and Responsibilities	Examples
Formative	• Improve learning • Inform instruction	• Student and teacher	• Lab report • Science lab demonstration • Teach-a-lesson
Summative	• Grading • Placement • Promotion • Accountability	• Teachers and external tests • External tests (and teacher)	• Multiple-choice • True-false • Fill in the blank

8) National Research Council. *Classroom Assessment and the National Science Education Standards*. Washington, DC: The National Academies Press. 2001: 26. https://doi.org/10.17226/9847.
9) Ibid, 39.
10) Ibid, 13.
11) Ibid, 34.

4) Research Methodology

Project Challenge

Leadership at a member institution approached the Forum with the following questions:

- What types of STEM programs do contact districts offer to middle school-level students?
- How did contact districts decide which STEM programs to offer?
- What implementation process did contact districts use for these STEM programs?
- What challenges did contact districts face when developing and implementing STEM programs?
- What standards serve as the basis of contact districts' middle school STEM programs?
- What teacher qualifications do contact district leaders select to run STEM programs?
- What effective methods or strategies do contact districts use for enhancing middle school-level students' learning in STEM programs?
- How do contact districts measure success in middle school-level STEM programs?
- Do contact districts see a measurable impact of STEM programs on middle school-level students' satisfaction, motivation or interest in school?
- Do STEM programs at contact districts increase students' engagement with STEM courses, programs, or opportunities at the high school level?

Project Sources

The Forum consulted the following sources for this report:

- EAB's internal and online research libraries (eab.com)
- The Chronicle of Higher Education (http://chronicle.com)
- National Center for Education Statistics (NCES) (http://nces.ed.gov/)
- National Research Council. *Classroom Assessment and the National Science Education Standards*. Washington, DC: The National Academies Press. 2001: 26. https://doi.org/10.17226/9847.
- "Topic Arrangements of the Next Generation Science Standards." *NGSS.* Accessed June 2, 2018. https://www.nextgenscience.org/sites/default/files/NGSS%20Combined%20Topics%2011.8.13.pdf.
- "Using Phenomena in NGSS-Designed Lessons and Units." STEM Teaching Tools. Accessed June 10, 2018. http://stemteachingtools.org/brief/42.
- *Huang, Wendy Hsin-Yuan, Dilip Soman, A Practitioner's Guide to Gamification of Education,* Rotman School of Management, University of Toronto, 10 December 2013, 15.
- "FAQS." Next Generation Science Standards. Accessed June 9, 2018. https://www.nextgenscience.org/.
- Planning for STEM Excellence, Carnegie STEM Excellence Pathway, Carnegie Science Center, 2015 http://www.carnegiesciencecenter.org/csc_content/stemcenter/pdf/pathway_1_pager_and_rubric_combo_2015.pdf

Research Parameters

The Forum interviewed program directors and coordinators of district-run mentorship programs for middle and high school students.

A Guide to Institutions Profiled in this Brief

Institution	Location	Approximate Enrollment
School A	Pacific West	840
Institution B	Mid-Atlantic	n/a
District C	Northeast	9,000
School D	Mid-Atlantic	750