EAB

DISTRICT LEADERSHIP FORUM

An Overview of K-8 Computer Science and Engineering Programs

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District Leadership Forum

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Research Methodology

Our research team spent five weeks reviewing the literature on engineering and computer science practices as well as broader STEAM programs for PreK-8 students. The goal of this research was to surface findings on common district practices surrounding these topics and how districts can effectively provide access to STEAM programming for students. If you have any questions about the research itself or our methodology, please reach out to your dedicated advisor.

Leadership at a partner district approached AskEAB with the following questions:

Engineering Questions

1. How do school systems define engineering practices?
2. How are school systems utilizing engineering practices to support content learning?
3. How are school systems measuring engineering outcomes PreK-8?
4. How are school systems educating professionals on using an engineering design process (EDP)? What model of the EDP are they using?

Computer Science Questions

5. How are other school divisions teaching computer science PreK-8?
6. What does current research say about how math understanding supports computer programming? How can integration of computer science in PreK-8 support math achievement for students?

STEAM Questions

7. How are school systems working to increase access to STEAM?
8. What curriculum resources are available and being used in school divisions PreK-6 for STEAM?
9. What role do grade level classroom teachers and specialists have in facilitating STEAM access?

1. Engineering

Districts Define Engineering Practices Similarly Nationwide

A review of the literature finds broad consensus among states, and therefore districts, in defining engineering practices for K-8 students. These shared definitions stem from the National Research Council's (NRC) "Framework for K-12 Science Education," which outlines three dimensions of robust K-12 science programming and forms the basis of the widely-used Next Generation Science Standards (NGSS).[1] These dimensions are: 1) eight core science and engineering practices to guide curriculum, instruction, and student practice, 2) seven crosscutting concepts identified by the NRC as fundamental to both science and engineering, and 3) core ideas that represent the most essential science topics for students to learn.

While the engineering design process (EDP) is a key piece of PreK-8 engineering curriculum, we discuss this topic in an upcoming section and focus first on how districts more broadly define engineering practices.

Given that most states use the NGSS or a comparable set of standards to mandate science and engineering education, many states share similar definitions of engineering practices.[2] For example, although Virginia is one of few states to use a science curriculum unaffiliated with the NGSS, its K-12 standards still incorporate six central science and engineering practices that are only slightly modified from those outlined in the NRC framework.[3] Several other states make adaptations to the NGSS standards but still include all eight original practices in their K-12 science curriculum (e.g., Massachusetts).[4]

Although the NRC framework begins in kindergarten, many states extend the same basic engineering practices to prekindergarten education (PreK). When paired with developmentally appropriate learning goals and simplifications to the engineering design process (EDP), students of all ages can engage in and benefit from the same foundational engineering practices. This cohesion across grade levels aligns with the recommendation of the National Academies of Sciences, Engineering, and Medicine to establish coherence between engineering education in the preschool through elementary grades.[5] Engineering practices for PreK students may also place greater emphasis on developing an emerging engineering mindset (e.g., collaboration, systems thinking) and making connections to children's problem-solving in out of school settings (e.g., informal learning opportunities in family settings).[6]

For an example, see this Science and Engineering Practices Progression Matrix outlining the progression in the complexity of standards and learning objectives from PreK through twelfth grade.

1) A Framework for K-12 Science Education. *National Research Council*
2) Transforming Science Assessment: Challenges and Recommendations for States. *Next Generation Science Standards*
3) Standards of Learning. *Virginia Department of Education*
4) Science and Technology/Engineering Learning Standards. *Massachusetts Department of Education*
5) Science and Engineering in Preschool Through Elementary Grades. *National Academies Press*
6) Engineering Education in Pre-Kindergarten through Fifth Grade: An Overview. *National Academies Press*

The eight foundational science and engineering practices identified by the NRC for K-8 students (and adapted by districts for PreK students) are as follows:

Key Science and Engineering Practices
From the National Research Council[7]

1. Asking questions (for science) and defining problems (for engineering)
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations (for science) and designing solutions (for engineering)
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

Engineering Practices Support Interdisciplinary Learning

Research finds that providing students with an integrated STEM education as opposed to isolated instruction in these subjects can result in deeper student understanding, achievement, and interest in STEM as a career field.[8,9] Specifically, research emphasizes engineering as a "fruitful approach to supporting children's overall learning and development…[and a] catalyst for early science and mathematics learning."[10] To this end, districts are beginning to see the value in using engineering practices to facilitate interdisciplinary STEM instruction or sometimes, integration into additional content areas beyond the STEM fields.

Notably, the National Academies finds the evidence to support productive interdisciplinary connections to be strongest in incorporating science and engineering with English Language Arts (ELA) and emergent in several other subjects, including computational thinking, social studies, and social-emotional learning (SEL).

For example, researchers at the **University of Wisconsin-Madison** developed six middle school curricular units that reinforce math and science standards through content centered around one of engineering's "Grand Challenges."[11] The Grand Challenges, established by the National Academy of Engineering, identify fourteen global challenges where engineering has the potential to fulfill a great societal need (e.g., restoring infrastructure, engineering better medicines). Each of the middle school units combines key elements of the engineering discipline (e.g., EDP, collaborative work) with math and science learning objectives, all presented in a real-world context with a humanitarian focus. A pilot study of these units in five Midwestern schools found that students receiving the Grand Challenges curriculum

7) A Framework for K-12 Science Education. *National Research Council*
8) Integrating beyond Content: A Framework for Infusing Elementary STEM-Focused Schools Components into Full-Service Community Schools. *Education Sciences*
9) Middle School Curricular Materials on Grand Challenges for Engineering: Impact on Efficacy and Expectancy Beliefs. *American Society for Engineering Education*
10) Engineering Education in Pre-Kindergarten through Fifth Grade: An Overview. *Committee on Enhancing Science and Engineering in Prekindergarten through Fifth Grades*
11) Middle School Curricular Materials on Grand Challenges for Engineering: Impact on Efficacy and Expectancy Beliefs. *American Society for Engineering Education*

often displayed more confidence in approaching math and science tasks and greater interest in STEM careers than the control group.

Another example of an integrated STEM curriculum comes from **Tracy Unified School District** (CA), which partnered with the nonprofit Community Training and Assistance Center (CTAC) to develop 52 integrated STEM units spanning grades PreK-12.[12] In units lasting approximately four weeks each, students undertake a design challenge through the EDP, produce a computational artifact, and focus on learning standards in math, science, and literacy. Teachers also assess student progress before, during, and after the unit and engage with how unit topics pertain to students' lived experiences. By integrating engineering into broader STEM instruction, these districts provide students the opportunity to engage with engineering in more varied and authentic ways that spark students' connection to and long-term interest in STEM fields.

Measuring Engineering Outcomes PreK-8

To measure student engineering outcomes, educators can both observe how student behaviors align with learning standards and assess further evidence of engagement in the EDP through artifacts, such as engineering notebooks.[13] In engineering notebooks, teachers should encourage students to document both their individual and team thought processes when approaching a specific engineering task and post-task reflections on the activity. Educators can also reinforce the practice of explicitly referencing the engineering practices used in classroom instruction throughout students' work in their engineering notebooks (e.g., steps for planning an investigation).

Given the popularity of the NGSS framework, many teachers also use NGSS-aligned evidence statements to observe student behaviors that demonstrate understanding of specific science and engineering standards. In addition to teacher assessment, teachers should look for evidence and examples that students have met each applicable standard. For example, in a second-grade unit on matter, students may be observed or asked to explain how they: "plan and conduct an investigation to describe and classify different kinds of materials by their observable properties" and "construct an argument with evidence that some changes caused by heating or cooling can be reversed and some cannot."[14]

See this webpage for a list of all NGSS-aligned K-8 evidence statements.

PreK-8 Curricula Centered on Engineering Design

According to the National Academies of Sciences, Engineering, and Medicine, engineering education for younger students centers mostly around engineering design, "an intentional, iterative activity to develop an object, system, or process that addresses a particular need, solves a particular problem, or accomplishes a particular goal."[15]

Students engage with engineering design through the engineering design process (EDP), which exists in several iterations of varying length and complexity. Many districts use an EDP model similar to the Museum of Science's popular "Engineering is

12) Frequently Asked Questions. *PreK-12 STEM*
13) Integrating Engineering Practices into K-12 Instruction. *McGraw Hill Education*
14) 2nd Grade Evidence Statements. *Next Generation Science Standards*
15) Engineering Education in Pre-Kindergarten through Fifth Grade: An Overview. *National Academies Press*

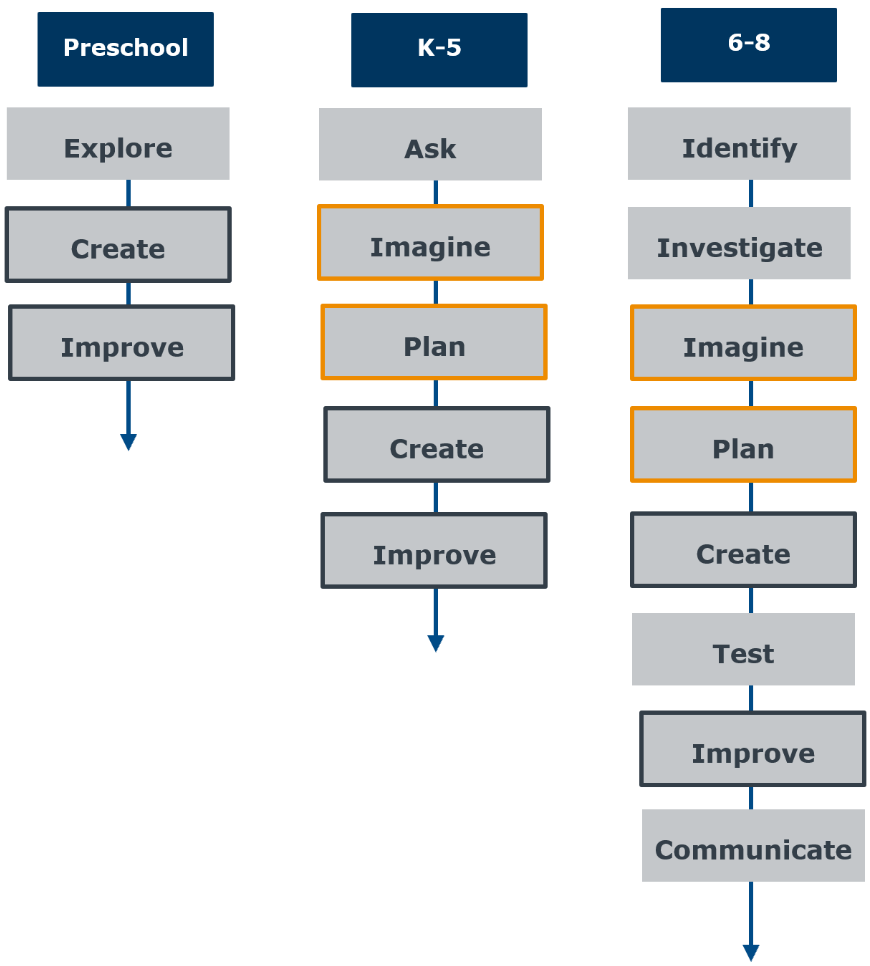
Elementary" (EiE) program, which provides three versions of the EDP to students based on their age. As illustrated below, preschoolers use a three-step process, K-5 students use a five-step process, and 6-8 students use an eight-step process, each of increasing complexity.[16,17]

Davis School District (UT) is one of several districts to use the age-appropriate versions of EiE resources for their K-8 students as part of a variety of supplemental STEM offerings.[18] Educators can find information about EiE as well as listings of which unit materials are available for use on the district website. Notably, research published in the Journal of Research in Science Teaching finds that the elementary version of the EiE program effectively increases students' engineering and science content learning more than a comparable science and engineering curriculum.[19]

The graphic below illustrates the increasing length and complexity of the EDP across grade levels as well as key steps in the process that remain consistent across grade bands.

Engineering Design Process Across Grade Levels

Engineering Is Elementary[20,21]



16) Science and Engineering in Preschool Through Elementary Grades. *National Academies Press*
17) The Engineering Design Process in K-12 Education. *New York City College of Technology*
18) Engineering is Elementary (EiE). *Davis School District*
19) The impact of engineering curriculum design principles on elementary students' engineering and science learning. *Journal of Research in Science Teaching*
20) Science and Engineering in Preschool Through Elementary Grades. *National Academies Press*
21) The Engineering Design Process in K-12 Education. *New York City College of Technology*

Educators Require Ongoing Support for EDP Integration

Districts that successfully educate professionals on using the EDP emphasize the importance of collaboration between staff, administrators, and community partners to provide teachers the confidence to adapt, develop, and teach engineering curricula for their classrooms. **Leading districts offer educators robust professional development both during initial implementation of new engineering curricula and on an ongoing basis post-implementation to provide educators the support they need**.

For example, as part of a grant-funded project in collaboration with the Boston Museum of Science, four Massachusetts school districts undertook a multi-year process to introduce specific units of the EiE curriculum in their elementary schools and provide the necessary professional development to elementary teachers.[22] The original implementation teams consisted of a lead teacher from each elementary school and supporting STEM faculty from local community colleges. The bulk of initial professional development took place at a three-day "Teacher Educator Institute" workshop at the Museum of Science, where teachers learned the engineering design process both through instruction and participation in the activities they would later conduct with their students.

A few weeks later, the community college STEM team met with each school district for a day-long planning session where teachers developed lesson plans together and communicated any needs for additional support.[23] Notably, the teachers and STEM team also developed two-year professional development plans (submitted to district administrators for approval) to train almost two hundred additional elementary teachers in the curriculum. The following summer, a group of lead teachers and STEM faculty reconvened to discuss implementation challenges and identify solutions for the upcoming school year.

Faculty from Virginia Tech also used robust pre- and post- unit implementation professional development sessions with middle school educators from **Montgomery County Public Schools** (VA) to develop a model for science and math teachers to integrate engineering design units into their classroom instruction.[24] The first part of these workshops reinforced inquiry-based instructional strategies while teachers experimented with sample hands-on EDP labs. Teachers then evaluated these lessons and learned to develop unique engineering units to integrate into their own classrooms. This is a key distinction from projects that simply provide teachers an engineering curriculum but do not build educator confidence or knowledge to move beyond pre-written curricula or develop additional integration opportunities for students.[25]

The Montgomery County teachers then implemented the engineering units over the school year with a university graduate student present in class to assist as necessary and to help evaluate instructional strategy. Implementation efforts were supplemented by mid-year and post-school year meetings, which provided teachers and university faculty the chance to reflect, lesson plan, and navigate the challenges and successes of integrating engineering design content into their curriculum.

One of the project's main outputs was the IBED template, which helps teachers identify open-ended problems that can form the basis of an engineering unit.

22) Teaching Engineering Across Elementary Schools. *American Society for Engineering Education*
23) *Ibid*
24) IBED: Inquiry by Engineering Design. *Virginia Tech*
25) Integrating science and engineering practices: outcomes from a collaborative professional development. *International Journal of STEM Education*

2. Computer Science

Districts Vary in Time and Structure of CS Content

Districts use a variety of content delivery models to provide PreK-8 students access to computer science programming. For example, in **San Francisco Unified School District** (CA), computer science specialists provide "push-in" instruction to PreK-5 students during one semester of the school year.[26] In the 6th-8th grades, students are required to take a computer science elective course taught by specialists for half of a semester. While the district acknowledges the advantages of integrating computer science into students' core curriculum, administrators find that using specialists to lead standalone classes is often more time and cost-effective than training all teachers to deliver CS content in core classes.

New York City Public Schools (NY) strives to provide all students with a minimum of one meaningful computer science unit (consisting of 10-25 hours of instruction) in each grade band (i.e., K-2, 3-5, 6-8).[27] Each unit integrates three main components:

- Computer science **perspectives** (i.e., "explorer", "innovator") that embody how students of different levels can approach CS programming. Each perspective roughly aligns with a K-12 grade band (e.g., "explorer" for K-2 students, "creator" for 3-5 students).
- Overarching computer science **concepts** (e.g., abstraction, algorithms) for the CS curriculum to center around.
- Specific computer science **practices** (e.g., analyzing, prototyping) to guide how students interact with CS programming.

The New York City Department of Education's "Computer Science for All" **website** includes guidance for both standalone CS instruction and interdisciplinary integration, such as this **webpage** that includes parallels between each computer science sub-concept and similar ideas in both math and English Language Arts (ELA). For example, the CS sub-concept decomposition (i.e., "ideas, problems, or projects are broken down into component parts to set the stage for deeper analysis") is compared to the ELA concepts of breaking down a word into syllables or an essay into distinct parts. Educators can use these interdisciplinary comparisons to familiarize students with new CS concepts or plan interdisciplinary CS and core subject units.

See this webpage for a table of all key computer science outcomes across grade levels.

Districts Emphasize Similar Computational Thinking Skills Across Models

Although districts may use slightly different models of computational thinking (CT), many emphasize similar skills. Common foundational practices are often based on a traditional four-part model of computational thinking (i.e., algorithm design, abstraction, decomposition, pattern recognition), with some districts adding additional practices such as debugging.

26) About Computer Science in San Francisco's Public Schools. *Computer Science for All in SF*
27) What is a Meaningful CS Unit? *NYC Department of Education*

According to the K-12 Computer Science Framework, "computational thinking refers to the thought processes involved in expressing solutions as computational steps or algorithms that can be carried out by a computer."

Districts often use computational thinking as the center of a broader computer science model that embodies larger goals for students' computer literacy, including inclusive computing practices and collaboration. One popular example of such a model is the K-12 Computer Science framework outlined below, where core practices 3-6 define the practice of computational thinking.[28] This framework informed the development of the Computer Science Teachers Association's (CSTA) K-12 Computer Science Standards, which several districts choose to adopt in full (e.g., Washington State uses the CSTA standards as its statewide CS standards).[29,30] Other districts may focus on similar concepts but package them in a district-specific learning sequence or framework for their students. For an example, see this **webpage** from San Francisco Unified School District outlining how nine key computational thinking practices will be introduced over the PreK-12 grade levels. These practices mirror the basic concepts of the K-12 CS framework or four-part CT model while using slightly different language to specify which skills or contexts the district will focus on.

Core Computer Science Practices

From the K-12 Computer Science Framework[31]

1. Fostering an inclusive computing culture
2. Collaborating around computing
3. Recognizing and defining computational problems
4. Developing and using abstractions
5. Creating computational artifacts
6. Testing and refining computational artifacts
7. Communicating about computing

Research Suggests Computer Science Can Bolster Students' Math Achievement

In terms of connections between computer science and mathematics achievement, several studies suggest that receiving computing instruction can lead to student performance gains in math.[32,33] Harry Cheng, Director of the UC Davis Center for Integrated Computing and Stem Educator (C-STEM), argues that including CS programming in math instruction can even help close the achievement gap because of its potential to help students overcome critical math struggle points, namely in algebra. According to Cheng, there is a mutually reinforcing relationship between algebraic and computational thinking and integrating CS with math "can give mathematical concepts context and relevance while still requiring the same amount of rigor as traditional mathematics instruction."[34]

28) Navigating the Practices. *K12 Computer Science*
29) K-12 Standards. *Computer Science Teachers Association*
30) Computer Science K-12 Standards. *Washington Superintendent of Public Instruction*
31) K-12 Standards. *Computer Science Teachers Association*
32) Understanding the Link between Computer Science Instruction and Reading & Math Performance. *ITiCSE 2021: 26th ACM Conference on Innovation and Technology in Computer Science Education*
33) Assessing Bootstrap: Algebra Students on Scaffolded and Unscaffolded Word Problems. *Brown University*
34) Teaching math with computer programming can help narrow achievement gap. *EdSource*

3. Increasing Access to STEAM Education

Provide Equitable and Varied Access Points to STEAM Subjects: A Case Study from Davis School District (UT)

Davis School District's "STEM-Centered Learning" approach provides all students with a selection of mandatory and optional STEM programming, in addition to policies and programs tailored to provide equitable access to students traditionally underrepresented in STEM fields.[35] We highlight several examples below:

- All district schools provide computer science programming for K-12 students, with elementary students receiving a minimum of half an hour of CS education weekly.
- The district operates a "Catalyst Center" for high school students and offers CTE programming in a variety of STEAM disciplines such as computer programming, graphic design, and pharmacy tech. The Center operates a week-long summer program for elementary students to explore a pathway of their choosing through hands-on activities led by the teachers.
- Davis School District operates five Math, Engineering, and Science Achievement (MESA) clubs that promote STEM involvement and achievement for underrepresented groups (i.e., female, minority, and economically-disadvantaged students). Students receive support from peers and industry mentors while participating in active learning activities designed to prepare students for their future college and career experiences.
- All students in sixth grade are encouraged to apply for the accelerated math program, either through a placement test or a math portfolio.

The district also uses several assessments and data-based decision-making tools to evaluate the integration of STEM content into core instruction and determine student access to quality STEM programming at each school. At a classroom level, administrators or fellow teachers conduct observations to identify how effectively educators teach through a STEM-centered lens, which emphasizes opportunities for students to participate in high-level thinking and take risks.

On both the school and district levels, administrators use qualitative and quantitative analyses to assess STEM program success and availability to students based on geographic school clusters to ensure program consistency and equity across the district. Qualitative interviews with elementary and middle school administrators provide insight into each cluster's STEM achievement and focus areas for growth. Administrators also report the number of STEM learning opportunities students receive in the classroom or in supplemental form (e.g., after school programs). These numbers are combined with reported measures of program effectiveness to form an opportunity score for each cluster and a deviation score based on the variance in opportunities offered to students at different schools in each group. These analyses provide valuable insights to guide future STEM programming and help inform the allocation of district funds to ensure more equitable access to STEM opportunities across each part of the district.

35) STEM-Centered Learning | 2021-2022 Summary Report. *Davis School District*

Make Curriculum and Instruction Relevant for All Students

In addition to policies that expand access to STEAM subjects, districts can use instructional and pedagogical strategies that maximize student learning and engagement. For example, research conducted with young students (PreK-3rd grade) finds that they benefit from "hands-on, play-based, and authentic engagement with STEAM subjects," which emphasizes student inquiry and autonomy.[36] Similarly, students of all ages can benefit from STEAM instruction presented through the student-centered learning framework (i.e., personalized learning, student agency and voice, competency-based education, real-world connections). This approach empowers all students to be leaders of their own learning and overlaps many of the elements central to a quality STEM education (e.g., encouraging student investigation, presenting instruction in real-world contexts).[37]

Mineola Public Schools (NY) includes several elements of student-centered learning in their K-8 curriculum, particularly through its STEAM integrated science labs. Used in conjunction with a more traditional science curriculum, these labs center around questions connecting students' experiences to the world around them to teach standards in science and additional disciplines, including social studies and social-emotional thinking (SEL).[38]

Role of Grade-Level Teachers and Specialists in Facilitating Access to STEAM

Teachers are vital to facilitating access to STEAM subjects, however they must overcome several barriers to ensure equitable instruction and support for all students. For example, many computer science teachers report barriers both in building a robust, equitable computer science classroom as well as seeing students' progress.[39] Many teachers feel that lack of school or district buy-in creates challenges, such as a lack of low-cost professional development opportunities for teachers to develop more advanced knowledge and lack of access to classroom resources. In addition, multiple sources indicate that most computer science and mathematics teachers are White, despite the diversity of the students they serve.[40,41]

Student-supplied barriers teachers face may include low student engagement or inadequate prior student exposure to STEAM subjects. In particular, teachers at schools with higher proportions of students traditionally underrepresented in STEM fields (e.g. Black, Indigenous, Latinx, and Pacific Islander students) cited students' lack of prior content knowledge as a barrier to student success in computer science courses.

Non-CS and non-STEM educators must also navigate significant challenges when transitioning to teaching integrated STEAM material. Focus groups with Nevada teachers whose schools received grants to implement STEM programs or curricular units revealed that virtually all the teachers felt insufficiently equipped to confidently teach STEM units to their students.[42] These themes persisted even in post-program interviews and manifested in teachers' struggles to make sense of and implement the STEM units, suggesting that experience with a STEM unit is not enough to result in confident STEM instruction. To ensure equitable access to STEM/STEAM programs for

36) Research and Policy Implications of STEAM Education for Young Students. *Education Commission of the States*
37) Integrating science and engineering practices: outcomes from a collaborative professional development. *International Journal of STEM Education*
38) Mineola Integrated Curriculum 23-24. *Mineola Public Schools*
39) The Computer Science Teacher Landscape: Results of a Nationwide Teacher Survey. *Computer Science Teachers Association*
40) Ibid.
41) Percentage distribution of teachers, by school type, race/ethnicity and selected main teaching assignment: 2017–18. *National Center for Education Statistics*
42) K-5 STEM Grants | Evaluation and Outcomes Report. *Nevada Governor's Office of Science, Innovation, and Technology*

students, districts first must invest in providing robust professional development, post-training support, and planning time for teachers consistently across the district.

These issues highlight the need for a multifaceted approach to increase equity and access to a quality STEAM education for PreK-8 students. Districts should prioritize recruiting and retaining a diverse STEAM teacher workforce that better reflects the diversity of the PreK-8 student population. Teachers should also (with district support) continue developing their knowledge through professional development opportunities, with a focus on student engagement and inclusion strategies and building teacher integration skills beyond the use of pre-written curriculum. Finally, districts must emphasize the importance of STEAM to student success by offering consistent and quality access to disciplines such as computer science and engineering to all students at all schools districtwide.

Free STEAM Resources

- The Multiple Literacies in Project Based Learning (ML-PBL) Curriculum develops students' math and literacy skills through science/engineering units. Each unit centers around a driving question which encourages students to engage in collaborative problem solving and elements of engineering design to create a solution.
- The Integrated Computational Thinking project provides sample activities which integrate computational thinking skills with language arts, social studies, or the arts.
- UC Davis's C-STEM Math/CS/Engineering Design Curriculum uses computing and robotics activities to facilitate mathematics learning with interdisciplinary projects in science, engineering, and the arts.
- Bootstrap offers computer science/data science modules for grade 5-12 teachers to integrate into math, science, or social studies classes.

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