TeachME PROFESSIONAL DEVELOPMENT
CEU's for Teachers and Educators

Innovation in STEM Education

About This Report

In 2015, the U.S. Department of Education, in collaboration with American Institutes for Research (AIR), convened a series of 1.5-day workshops that brought together invited experts and thought leaders in science, technology, engineering, and mathematics (STEM) teaching and learning to share their ideas and recommendations for an innovative future of STEM education. Nearly 30 individuals, representing a wide range of expertise, contributed to this project. These individuals were selected based on their work in the areas of learning sciences research, culturally relevant teaching and learning, equity and access, assessment and measurement, preschool through 12th-grade (P–12) education, higher education, education technology, afterschool and informal STEM learning, and community networks of learning. This report synthesizes the key observations, considerations, and recommendations put forth by the workshop participants under the auspices of an aspirational vision for STEM education, or "STEM 2026."

Executive Summary

Building on the priority to support science, technology, engineering, and mathematics (STEM) education set by the Obama Administration that is reflected in several of the Administration's initiatives, the U.S. Department of Education (the Department) is releasing a report outlining a vision to carry on that legacy in the coming decade. This vision was informed by the key observations, considerations, and recommendations put forth by a varying range of STEM education thought leaders and experts from the field during a series of 1.5-day workshops convened by the Department in collaboration with American Institutes for Research (AIR). This report is a resource that provides examples, not endorsements, of resources that may be helpful in reaching the STEM 2026 vision as outlined by the field experts.

The complexities of today's world require all people to be equipped with a new set of core knowledge and skills to solve difficult problems, gather and evaluate evidence, and make sense of information they receive from varied print and, increasingly, digital media. The learning and doing of STEM helps develop these skills and prepare students for a workforce where success results not just from what one knows, but what one is able to do with that knowledge. Thus, a strong STEM education is becoming increasingly recognized as a key driver of opportunity, and data show the need for STEM knowledge and skills will grow and continue into the future. Those graduates who have practical and relevant STEM precepts embedded into their educational experiences will be in high demand in all job sectors. It is estimated that in the next five years, major American companies will need to add nearly 1.6 million STEM-skilled employees (Business Roundtable & Change the Equation, 2014). Labor market data also show that the set of core cognitive knowledge, skills, and abilities that are associated with a STEM education are now in demand not only in traditional STEM occupations, but in nearly all job sectors and types of positions (Carnevale, Smith, & Melton, 2011; Rothwell, 2013).

The nation has persistent inequities in access, participation, and success in STEM subjects that exist along racial, socioeconomic, gender, and geographic lines, as well as among students with disabilities. STEM education disparities threaten the nation's ability to close education and poverty gaps, meet the demands of a technology-driven economy, ensure national security, and maintain preeminence in scientific research and technological innovation.

In recognition of the widening skills and opportunity gaps in STEM, the Obama Administration has initiated several efforts to motivate action. In 2010, President Obama announced the launch of Change the Equation, a CEO-led effort to improve STEM education, as part of the Administration's larger Educate to Innovate campaign. In addition, under this Administration, the Committee on STEM Education (CoSTEM), comprised of several federal agencies—including all mission-science agencies and the Department—is facilitating a cohesive national strategy to increase the impact of federal investments in STEM teaching and learning. In 2013, CoSTEM put out a Five-Year Federal Science Technology, Engineering, and Mathematics Education Strategic Plan. In January 2016, Obama announced a bold Computer Science for All initiative; and the Elementary and Secondary Education Act (ESEA), as reauthorized under the Every Student Succeeds Act (ESSA) in December 2015, identifies all four STEM disciplines, including engineering and computer science, as fundamental components of a well-rounded education for all children. ESSA also includes provisions to promote local innovation and investments in what works to improve STEM teaching and learning. These are just a few examples of the focused attention being placed on STEM at the national level to generate change and improvement at the state and local levels.

This report is a complementary effort, resulting from a Department-led effort to gain insight into the latest research and thinking about how to improve STEM teaching and learning, including how to ensure the engagement and success of the full diversity of the nation's learners. In 2015, the Department, in collaboration with AIR, invited nearly 30 experts and thought leaders in STEM teaching and learning to participate in a series of discussion-based workshops to exchange ideas and develop recommendations for the future of STEM education. The project contributors were asked to draw from their own experiences, and their knowledge of the evidence behind examples of innovative and promising new approaches taking hold in communities across the nation.

This report summarizes the results of these workshop discussions and outlines what emerged from the experts' recommendations; namely, an aspirational vision (hereafter referred to as "STEM 2026") for STEM education to promote lifelong learning among all youth and in all communities. In recognition of the challenges to transforming STEM education on a large scale, the STEM 2026 vision presented in this report is meant only as starting point upon which key stakeholder groups, including policymakers, researchers, educators, and industry leaders, as well as the broader public, can build. The goal of this vision is not to establish a prescribed set of activities but to motivate actions, including the development of communities of practice (CoP), that help build a stronger evidence base for what STEM teaching and learning experiences work best in particular contexts and to serve diverse learners.

The remainder of this report describes in more detail the six interconnected components of STEM 2026, and the challenges and opportunities for innovation related to converting these components into widespread practice:

- **Engaged and networked communities of practice.** All schools, early learning programs, communities, and students engage in CoP that draw on the knowledge, tools, resources, and expertise needed to effectively engage in STEM teaching and learning experiences, in and outside of formal school settings. These collaborative networks of STEM learning foster the skills and growth mindsets among all students that lead to lifelong learning and opportunities for postsecondary and career success, while expanding access to rigorous STEM courses, including computer science.
- **Accessible learning activities that invite intentional play and risk.** STEM 2026 emphasizes the benefits of inviting intentional play into the learning process in P–12 and at the postsecondary level. Activities that are designed to incorporate intentional play are applicable at all levels of the education continuum. These activities offer low barriers to entry and encourage creative expression of ideas, while still engaging diverse students in complex and difficult content. In STEM-themed play, young people's desire to design and create motivates curiosity in STEM and fosters a sense of belonging as students learn from and with others, and are encouraged to think in divergent ways. Through the process of exploration and discovery, they see that STEM is everywhere, that they have something to contribute to the field, and they learn to take a team-based approach to tackling real-world problems and challenges.
- **Educational experiences that include interdisciplinary approaches to solving "grand challenges."** STEM education engages students of all ages in tackling grand challenges. Grand challenges are those that are not yet solved at the local community, national, or global levels. Grand challenges may include, for example, water conservation or improving water quality; better understanding the human brain to uncover new ways to prevent, treat, and cure brain disorders and injury; developing new technology-enabled systems for improving access to health care; addressing aging infrastructure; or making solar energy cost competitive and electric cars that are affordable (Office of Science and Technology Policy, n.d.). Tasking children and youth with a grand challenge helps them understand the relevance of

STEM to their lives and to see the value of STEM in addressing issues that better their own lives and the lives of others. Grand challenges also offer a platform for incorporating culturally relevant approaches and content into STEM instruction.

- **Flexible and inclusive learning spaces.** Learning spaces that offer teachers and students flexibility in structure, equipment, and access to materials, including spaces that are located in the classroom, in the natural world, makerspaces, and those that are augmented by virtual and technology-based platforms can enhance learners' STEM experiences. Diversifying when and where learning occurs promotes opportunities for culturally relevant pedagogies and activities by facilitating new modes of exploring STEM concepts and developing STEM skills. Flexible learning spaces are adaptable to the learning activity and invite creativity, collaboration, co-discovery, and experimentation in accessible and unintimidating instructor-guided environments.
- **Innovative and accessible measures of learning.** As President Obama has said, the nation needs to rethink its approach to testing to ensure that students are taking fewer, smarter, and better tests. Achievement and performance assessments, when approached thoughtfully, can play a role in assessing and measuring STEM learning at key milestones in students' education pathways. In addition, they play a role in identifying achievement gaps among groups of students, schools, districts, and geographic locations. At the same time, these types of tests should be carefully calibrated to ensure they are not redundant, do not take up too much classroom time, and are giving educators reliable unbiased information about student learning. In the STEM 2026 vision, there also is recognition of the value of more formative measures of learning that provide insight into the mindsets and habits associated with academic and postsecondary outcomes, including those that can be drawn from observations, evaluation of portfolios of student work, and student demonstrations and presentations.
- **Societal and cultural images and environments that promote diversity and opportunity in STEM.** In STEM 2026, how STEM is messaged to youth and their families is transformed. Research shows that repeated exposure to images, themes, and ideas affect people's beliefs, behaviors, and attitudes (Handelsman & Sakraney, 2015). In STEM 2026, popular media, toy developers, and retailers consider issues of racial, cultural, and gender diversity and identity in portrayals of STEM professionals and STEM-themed toys and games. These images counter historical biases that have prevented the full participation of certain groups of individuals in STEM education and career pathways. These portrayals include diverse pictures, descriptions, or images of what STEM work entails, including the array of jobs and activities that use STEM; and who is seen doing and leading STEM-related work. Communities and youth in all neighborhoods and geographic locations around the country are equally exposed to social and popular media outlets that focus on STEM, and a wide diversity of STEM-themed toys and games that are accessible and inclusive and effectively promote a belief among all students that they are empowered to understand and shape the world through the STEM disciplines.

The contributors to STEM 2026 acknowledge that developing and achieving a forward-thinking approach to STEM education is a complex and evolving task. The project team and contributors expect and trust that the STEM 2026 vision described here will be revised and refined as new knowledge, evidence, and experiences are gained in the process of achieving it.

[1] For the purposes of this report, the STEM 2026 vision that developed out of the contributions of field experts includes computer science in its understanding of what constitutes a strong STEM education, consistent with ESSA.

[2] See, for example: https://www.whitehouse.gov/the-press-office/2016/06/21/impact-report-100-examples-president-obamas-leadership-science; https://www.whitehouse.gov/issues/education/k-12/educate-innovate; and https://www.whitehouse.gov/sites/default/files/docs/giving_every_child_fair_shot_050316.pdf

[3] See, for example: Bailey, Kaufman, & Subotic, 2015; Betrus, 2015; Dweck, Walton, & Cohen, 2014; and Sharples, 2000.

[4] More information and resources about ESSA, including major STEM provisions included in the bill, are available at http://www2.ed.gov/policy/elsec/leg/essa/index.html?src=essa-resources

Introduction

Understanding the Need for a Bold Vision in Science, Technology, Engineering, and Mathematics (STEM) Education for Lifelong Learning

This report describes a vision (hereafter referred to as "STEM 2026") for the future of STEM education, preschool–12th grade (P–12) and beyond. STEM 2026 is aspirational but builds on the priorities the Obama Administration has established on improving innovation and equitable access to high-quality learning experiences in these critical fields. The key components of the vision resulted from a series of workshops and discussions held in 2015 that were organized by the U.S. Department of Education (the Department), with support from American Institutes for Research (AIR). Nearly 30 individuals representing a wide diversity of expertise, experience, and perspectives were invited to exchange knowledge and ideas for leveraging the opportunities of today to design a possible future of STEM education. This vision is not intended to prescribe a set of activities or practices. Rather, STEM 2026 is meant to start a conversation about opportunities for innovation, and propel research and development that can build a stronger evidence base for what works in various contexts, best serves diverse learners, and motivates action toward achieving transformative change.

As recognized in the Every Child Succeeds Act (ESSA), President Obama's Computer Science for All initiative, and the competitive priority to focus attention on STEM in several of the Department's discretionary grant programs, STEM is a crucial component of a well-rounded education for all students—an education that provides access to science, social studies, literature, the arts, physical education and health, and the opportunity to learn an additional language. The process of learning and practicing the STEM disciplines can instill in students a passion for inquiry and discovery and fosters skills such as persistence, teamwork, and the application of gained knowledge to new situations (Bailey et al., 2015; Betrus, 2015). Experts contend that these are the types of growth mindsets and habits that demonstrate one's capacity for academic tenacity and lifelong learning in a rapidly changing world (Dweck, Walton, & Cohen, 2014; Sharples, 2000).

A strong STEM education—one that results in the skills and mindsets just described and opens the door for lifelong learning—starts as early as preschool, is culturally responsive, employs problem- and inquiry-based approaches, and engages students in hands-on activities that offer opportunities to interact with STEM professionals. The development of and adherence to these types of STEM teaching and learning practices is not widespread, however, and opportunity gaps persist throughout the education system. The inequities in STEM education along racial and ethnic, linguistic, cultural, socioeconomic, gender, disability, and geographic lines are especially troubling because of the powerful role a foundational STEM education can play and because the gaps are so pronounced in STEM. According to the U.S. Department of Education Office for Civil Rights' Issue Brief *Civil Rights Data Collection: Data Snapshot: College and Career Readiness* (2014), the STEM fields "are the gateway to America's continued economic competitiveness and national security, and the price of admission to higher education and higher standards of living for the country's historically underrepresented populations" (p. 2). Recent analyses indicate that during the next five years, major American companies will need to add a total of nearly 1.6 million employees to their workforce: 945,000 who possess basic STEM literacy and 635,000 who demonstrate advanced STEM knowledge (Business Roundtable & Change the Equation, 2014).[5] Other data suggest that at least 20 percent of U.S. jobs require a high level of knowledge in any one STEM field (Rothwell, 2013).[6] Even outside of the traditional STEM job sector, there is a need for STEM competencies and skills. Data show that the set of core cognitive knowledge, skills, and abilities that are associated with a STEM education are in demand in nearly all job sectors and occupations (Carnevale, Smith, & Melton, 2011; Rothwell, 2013).

Presently, policies and practices that ensure equitable access to the best STEM teaching and learning are not widespread. States, districts, and schools struggle to provide all students with the STEM experiences required for the 21st century, regardless of college and career aspirations. In particular, state and local education agencies and school-level educators struggle to close persistent achievement gaps in core subjects like mathematics and science. National Assessment of Educational Progress (NAEP)[7] results, for example, show that, compared with 43 percent of White students and 61 percent of Asian students, just 13 percent and 19 percent of Black and Hispanic students, respectively, are scoring at or above proficiency in eighth-grade mathematics.

NAEP data also show that other underrepresented groups also perform below their White and Asian peer groups. In eighth-grade science, 45 percent and 46 percent of White and Asian students, respectively, perform at or above proficiency, compared with 20 percent or less of racial and ethnic minorities. NAEP performance gaps in mathematics and science also are evident by gender and are troublingly stark by student disability, English learner (EL) status, and free or reduced-price lunch eligibility status. Eighth-grade students with disabilities and students eligible for free or reduced-price lunch scored nearly 30 points below their peers in science and mathematics; EL students, nearly 40 and 50 points below their peers in mathematics and science, respectively. Although gaps are narrowing in mathematics between girls and boys, performance trends over time continue to show higher percentages of males than females scoring at or above proficiency in the last 10 years. In science, the gender gaps have remained largely static from 2009–2011.

Data show that rural schools also are especially challenged in meeting student performance benchmarks in mathematics and science. Rural children from lower socioeconomic status families often start kindergarten with lower mathematics achievement and make less progress during elementary and middle school than their suburban and urban peers (Graham & Provost, 2012). Rural schools typically are challenged in their education improvement efforts by geographic isolation, fewer numbers of experienced teachers, and fewer resources (Boyer, 2006).

At the high school level, both in these rural communities and across the nation in more urban and suburban centers, many students are not even provided with the courses they need to develop and deepen their mathematics and science interests, skills, and knowledge. The U.S. Department of Education's Office for Civil Rights (OCR) examined student access to and participation in mathematics and science courses across the nation's schools, with unsettling findings. Only half of the nation's high schools offer calculus, and only 63 percent offer physics. Even the core set of high school math and science courses, including Algebra I and II, geometry, biology, and chemistry, is absent in at least 10 percent–25 percent of the nation's high schools. There also are remarkable inequities in the availability and access to these courses. White and Asian students are more likely to attend schools that have the full range of mathematics and science courses, compared with their underrepresented minority peers. For example, just 66 percent of schools with the highest percentages of Black and Latino students offered chemistry, compared with 78 percent of schools with the lowest percentages of Blacks and Latinos. For Algebra II, the percentages are 74 percent and 83 percent, respectively (U.S. Department of Education, OCR, 2014).

States and districts also are challenged to promote the widespread adoption of emerging best practices such as adequately encouraging the participation of historically underrepresented groups in career and technical education (CTE) programs; integrating developmentally appropriate STEM experiences into early childhood education; and equitably engaging all students, including ELs, students with disabilities, students from low-income households, rural students, racial and ethnic minority students, and girls in STEM subjects like engineering and computer science. High-quality, culturally relevant, and innovative STEM teaching and learning, across the P–12 system, typically occurs in select communities and schools—usually those that have the most resources and access to knowledge and expertise, and the infrastructure to implement innovative tools, technologies, and STEM-career-specific postsecondary pathway programs like CTE. Moreover, especially at the middle and high school levels, many of the cutting-edge STEM-focused subjects, if offered at all, are encouraged for students only at certain grade levels who meet specific performance metrics and only available in highly resourced schools and communities (Californians Dedicated to Education Foundation, 2014).

These gaps are not new; they reflect long-standing patterns in resource allocation, student performance and access that have been widely acknowledged. Certainly, the federal, state, and local governments; the private sector; and advocacy groups have placed a high priority on developing policies and practices to close these gaps. As of yet, however, the combined efforts of these agencies and organizations have not produced success on a large scale.

In STEM, the funding and availability of high-quality programming continues to be inconsistent, favoring schools and communities that have access to the most resources, knowledge, and expertise. In addition, strong STEM pedagogy and resources are typically lacking in schools serving disadvantaged students, and many of the programs that are available aim to address a perceived deficit with the student, rather than a focus on changing the system and delivery of STEM instruction to more effectively support and draw on students' strengths (The Leadership Conference on Civil and Human Rights and The Leadership Conference Education Fund, 2015).

Compounding the issues caused by the long-standing structures of STEM education and traditional funding mechanisms for STEM programs, there is limited familiarity and understanding among the broader public of the "STEM" acronym as well as misconceptions about STEM education, including when, how, and to whom to teach these disciplines (Volmert, Baran, Kendall-Taylor, & O'Neil, 2013). In education, even among experts in the field, definitions and understandings of what STEM education means differ. According to a report by the National Academies Press (2014), *STEM Integration in K-12 Education: Status, Prospects, and an Agenda for Research,*

> In educational practice and in research, the term *integrated* is used loosely and is typically not carefully distinguished from related terms such as *connected, unified, interdisciplinary, multidisciplinary, cross-disciplinary,* or *transdisciplinary*. Defining integrated STEM education is further complicated by the fact that connections can be reflected at more than one level at the same time: in the student's thinking or behavior, in the teacher's instruction, in the curriculum, between and among teachers themselves, or in larger units of the education system, such as the organization of an entire school (p. 23).

In light of the unanswered questions and ambiguity about what STEM education, particularly an integrated STEM education means and looks like, STEM instruction remains typically stove-piped in current practice, guided by traditional course pathways that place "math as part of the basics, science as important but secondary, and technology and engineering as supplementary add-ons that are only appropriate 'later' and for 'some students'" (Volmert et al., 2013, p. 5). Although there are important differences between the STEM disciplines, including among the strategies that are optimal for learning the different STEM subjects, research suggests that an interdisciplinary approach can enhance students' learning and better model STEM processes in the real world (Volmert et al., 2013, p. 5). The assumption that technology and engineering experiences should be available only for those "who are naturally gifted in STEM subjects" also stymies innovative approaches to teaching and learning that could benefit all students (Volmert et al., 2013, p. 5). In sum, the perceived elitism of STEM among members of the public, combined with uncertainty about integrated STEM instruction, perpetuates "deterministic views of genetics or stereotypic ideas of culture" and fails to recognize the benefit of STEM education in promoting higher level critical thinking skills and lifelong civic engagement, regardless of a student's post-secondary plans and career aspirations (Volmert et al., 2013, p. 5).

Despite the many challenges associated with transforming STEM education in this country, the enhanced priority being placed on STEM education, including within CTE in recent years, coupled with initiatives underway by public, private, and government entities to promote greater equity in STEM academic and career pathways and CoP around shared goals, suggest that the nation is well positioned for implementing innovative approaches to STEM teaching and learning. Still, many any may ask: How can the nation move the needle dramatically enough to provide all students greater equity of access to high-quality STEM learning experiences?

STEM 2026 helps lay the foundation for answering this question. As mentioned earlier, recognizing the need and opportunity for innovation and improvement in STEM education, the Department, in collaboration with AIR, convened a group of experts in a series of knowledge exchange workshops to build on the legacy of the Obama Administration's STEM education efforts. These workshops were designed with a DARPA (Defense Advanced Research Project Agency) approach in mind. The DARPA model is premised on setting a bold vision and goals for the future with the intent of guiding research and policy forward. It has been used by the U.S. Department of Defense (DoD) with evidence of success. The model combines basic and applied research by bringing together diverse teams of experts to "iterate continuously on basic research challenges aimed at solving enormously complex problems" related to national security (Shilling, 2015, para 3). In recognition of the promise the DARPA approach holds for promoting innovation in education, the Obama Administration's budget proposals have included funding for an *ARPA-ED* (Advanced Research Projects Agency for Education), although such an agency has yet to be established. An ARPA-ED remains a potentially worthy aspiration for a future administration, as it could serve as a vehicle to stimulate the kinds of research, insights and new practices that are necessary to effectively serve diverse learners in local contexts.

With the DARPA model in mind, the nearly 30 contributors to the project shared their ideas. Their observations, considerations, and recommendations for transforming STEM education through the application of learning sciences research; culturally relevant, inclusive, and accessible learning experiences; technology to enhance and expand learning; early and frequent exposure to STEM in formal and informal settings; and networked systems of STEM learning in all of the nation's communities serve as the foundation for the STEM 2026 vision. This vision is meant only as a starting point for change, a foundation upon which a stronger evidence base for the approaches and experiences that work best in particular contexts and to serve and effectively engage diverse learners can be built.

[5] According to Business Roundtable and Change the Equation (2014), "'Basic STEM literacy' refers to foundational science, technology, engineering and math skills that all U.S.-educated working-age adults should possess. 'Advanced STEM knowledge' refers to science, technology, engineering and math knowledge and skills typically taught in post-secondary institutions as preparation for specialized occupations that require deeper STEM knowledge" (p. 7).

[6] The report (Rothwell, 2013) used a method for identifying the level of STEM knowledge required for each occupation using the knowledge requirements scores for STEM fields obtained from O*NET, an ongoing project funded by the Department of Labor to provide occupational information in the United States. For an occupation to be classified as requiring a high level of STEM knowledge in one field, it must have an O*NET knowledge requirements score of 1.5 standard deviations in the given field.

[7] http://www.nationsreportcard.gov data are presented for the most recent data available on the NAEP Website: 2015 for mathematics; 2011 for science.

The STEM 2026 Vision

STEM 2026 envisions high-quality, culturally relevant STEM learning experiences for every child and young person. In STEM 2026, students have access to and possess a sense of belonging in STEM and lifelong learning pathways that extend across formal and informal P–12 and higher education settings, including schools, science centers, and other STEM-rich institutions. STEM 2026 includes six interconnected components:

- Engaged and networked communities of practice
- Accessible[8] learning activities that invite intentional play and risk
- Educational experiences that include interdisciplinary approaches to solving "grand challenges"
- Flexible and inclusive learning spaces supported by innovative technologies
- Innovative and accessible measures of learning
- Societal and cultural images and environments that promote diversity and opportunity in STEM

In the process of identifying the key components of STEM 2026, the contributors to this project grappled with the issue of how the vision could be equitably implemented across the diversity of communities that exist in the United States. Throughout this report, the variation in challenges and opportunities that exist in local contexts with respect to these six components of the vision are discussed. Achieving the goals of STEM 2026 is contingent on the actions of multiple stakeholder groups and the development of CoP that can support the integration and institutionalization of innovative teaching and learning practices within local organizational and cultural contexts.

CoP actively engage key stakeholder groups in a process of collective learning that is structured around a shared mission. Through regular interaction, these groups of people build relationships, jointly implement activities, and share information with each other that advances the achievement of their common goal (Wenger-Trayner & Wenger-Trayner, 2015). As such, CoP could play a critical role in transforming the cultural and institutional environments that presently promote stereotyping and implicit bias about who can excel in STEM fields into inclusive learning environments that welcome intellectual diversity of knowledge and thought.

In the next sections of this report, the key components and guiding principles of STEM 2026 are described. Integrated throughout these sections are illustrative examples of what these components could look like in practice. Some of the examples were imagined by our contributors; some are in practice now, with emerging levels of evidence of promise and effectiveness. These examples were selected for inclusion in this report because they reflect the types of innovation that research is beginning to show can positively affect equitable access, engagement, and outcomes in STEM teaching and learning. Where available, this report includes links to specific evidence of a program or tool that is directly mentioned. Notably, these examples represent just a small number of the many innovative efforts that are being implemented across the nation to improve STEM education.

THE STEM 2026 VISION

INNOVATIVE MEASURES OF LEARNING

Academic improvements over time

Developing critical thinking skills

Collaboration and building necessary social skills

Facility with core knowledge

Hard work and tenacity

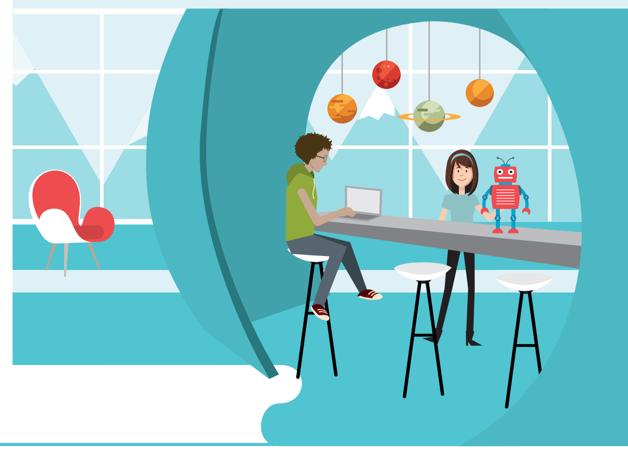
Modeling authentic problems

Learning by trial and error and individual exploration

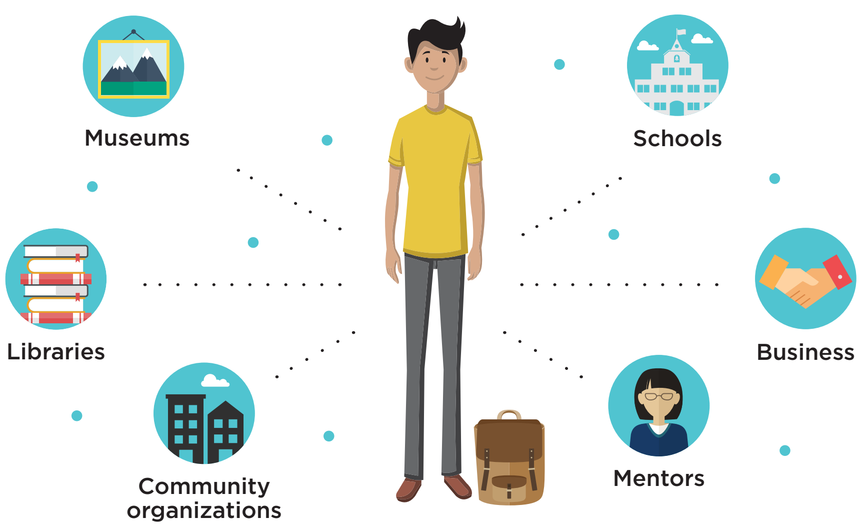
FLEXIBLE LEARNING SPACES

SOLVING RELEVANT GRAND CHALLENGES

ACCESSIBLE ACTIVITIES THAT INVITE PLAY & RISK



ENGAGED & NETWORKED COMMUNITIES OF PRACTICE



PROMOTING DIVERSITY

Engaged and Networked Communities of Practice

In STEM 2026, networked CoP provide consistent exposure to STEM through the support of teachers, school and early childhood program leaders, and school- and community-based role models. These mentors encourage students to learn about the world around them; to identify challenges at the local, national, and global levels; and to use what they learn and observe to develop innovative solutions to these challenges. These formal and informal educators harness perhaps one of our greatest assets in transforming STEM education—children's curiosity. As noted by one contributor to the project: "Children are born curious and come equipped with a desire to learn that rivals even the most determined scientist."

As with all aspects of education, the entire community plays a critical role in demonstrating the relevance and value of STEM in everyday life and in promoting exposure and equitable access to high-quality STEM learning experiences. The engagement of the full range of stakeholders and community members in improving STEM education in particular contexts can help mitigate the behavioral, structural, and organizational factors that affect STEM teaching and learning practices that play a role in engaging or turning certain groups of learners away from STEM pathways (Handelsman & Sakraney, 2015). Implicit biases that adversely affect certain groups of individuals are particularly challenging to combat since, unlike explicit biases that involve consciously held beliefs and attitudes about a particular group, implicit bias "is activated automatically and unintentionally, functioning primarily outside of a person's conscious awareness" (Handelsman & Sakraney, 2015, p. 1). Fortunately, an increasing amount of attention has been placed on implicit biases in the education system, particularly in the STEM disciplines; and resources exist that CoP can tap as they advance their efforts to engage all students in productive and meaningful STEM learning experiences.[9] As described next, some examples of CoP approaches to transforming STEM education that may be helping to reduce implicit biases are being established across the nation.

In Pittsburgh, Remake Learning is a professional network of educators and innovators working together to leverage their resources and talents in ways that provide and improve access to engaging teaching and learning experiences for everyone in the community. The Children's Museum of Pittsburgh, one of the more than 250 members of the network, has a MAKESHOP® space that provides a variety of ways for children and families to make, play, and design using the same tools used by professionals in a field. Physical materials and digital media resources are available, and visitors are encouraged to use and interweave these materials and resources in creative and experimental ways. Skilled makers are on-site to guide and assist visitors in the making process. As another example of how the museum is working within Remake Learning to promote an engaged and networked community of learning, it offers two prekindergarten Head Start classes on-site through Pittsburgh Public Schools.

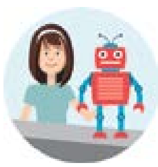
TEXT BOX 1. THE ALASKA RURAL SYSTEMIC INITIATIVE

Native communities have a complicated relationship with the education system because of a legacy of assimilation and loss of cultural identity. Native populations, including Alaska Natives, have a long history of teaching and learning experiences that were meant to "inculcate the knowledge and values of Western society" and essentially destroy native cultures by "breaking down the bonds of language and tradition that had sustained people on a land they knew well" (Boyer, 2006, p. 10). The Alaska Rural Systemic Initiative (RSI) took a new approach to re-engaging Alaska Native communities in the education system and better serving native youth. First, it documented cultural knowledge and affirmed its value in modern society. More specifically, it acknowledged the legitimacy of native knowledge systems, including native conceptions of and approaches to science. The project did this by sponsoring a series of sessions that examined the meaning of mathematics and science in the Alaska Native world and resulted in specific recommendations from 60 Alaska Native leaders and educators for improving mathematics and science education in public schools. The sessions also led to the development of a council of elders to help guide the reform effort. Critical to the project's success was its systemic approach to reform, including the engagement and support of complementary local initiatives aimed at achieving the RSI goals. These complementary activities were peer support for teachers, the development of culturally appropriate curriculum materials, summer camps and science fairs, and the school-community collaborations that include community elders.

As another example, the National Science Foundation's (NSF's) Rural Systemic Initiative (RSI)[10] was a prior federal agency effort that focused specific attention on the nation's most rural and historically impoverished regions of the United States. The $140 million dollar program, which ran from 1994–2008, represents one of the most significant federal efforts to address recognized inadequacies in mathematics and science education in rural America (Harmon & Smith, 2012). Although no longer in place, the RSI program is notable in its reach and design, and could serve as a model for future efforts to ameliorate the inequities in STEM education for students in rural communities. RSI supported more than 300 of the 400 or so counties that are identified as highly rural (Boyer, 2006). The goal of the initiative was to improve mathematics, science, and technology education in these communities, including those in coastal Virginia and the Carolinas, the Gulf Coast, Appalachia, the Ozark region, Alaska, rural Hawaii, regions of Texas, and several Native American reservations (Boyer, 2006). RSI recognized the socioeconomic complexities of educational inequity in rural America that could not be addressed merely through an influx of money and classroom resources. Specifically, the program was designed to understand and align the unique values, strengths, and culture of a given community with the values of the education system, thereby developing sustainable networks of learning (Boyer, 2006). RSI-funded projects leveraged local leadership and the assets of the families to support the development of communitywide, cross-sector partnerships that "address[ed] larger issues of school governance, cultural survival, and local economic development," thereby leading to improved mathematics, science, and technology test scores, and student enrollment in advanced STEM courses and postsecondary education (Boyer, 2006, p. 4).

RSI models of change varied from one community to another, but each focused on capacity building at the local level. According to a retrospective examination of the program that drew on data from focus groups, interviews, and surveys of project participants as well as student achievement data, RSIs were overall successful in assisting districts in implementing mathematics and science curricular, instructional, and assessment practices that had not previously been in place; providing teachers with access to high-quality professional development and networking experiences; and leveraging resources from multiple external sources (Harmon & Smith, 2012). (See Text Box 1. The Alaska Rural Systemic Initiative for a description of one RSI-funded project.)

These are just two examples that illustrate what the contributors to this project envisioned occurring more broadly across the nation. Importantly, in working to spread and propagate networks like these, strategies and policies must be enacted to ensure that district, school, and community leaders have the designated time, knowledge, connections, and resources they need to proactively promote equitable access and participation in the networked system. It is only through such assurances, including grants and other funding opportunities that target and reach historically disadvantaged and educationally underresourced communities, that the potential of STEM 2026 will be realized.



Accessible Learning Activities That Invite Intentional Play and Risk

Often absent from the culture and structure of the formal education system, particularly in the middle and secondary grades, is the recognition that hands-on experience, including experience of failure, plays an essential role in learning academic subjects. STEM education in formal school settings does not consistently promote some of the core values and practices of science and engineering in practice; namely, searching for uncertainty, recognizing ambiguity, and learning from failure (Camins, 2012). In reflecting on what STEM education should encourage, contributors to this project described a process of wonder and discovery; playful, hands-on investigation; learning from failure; and an enterprise that allows youth to marry their convictions and enthusiasms with opportunities to grow.

Intentional play activities can support this type of learning experience by providing students with time to explore their uncertainties, construct knowledge from experience, and strengthen relationships (Bertrus, 2015; Nell, Drew, & Bush, 2013; NYCSI, 2014). Early childhood and early elementary education; structured events like school, state, regional, and national science fairs; as well as informal learning settings such as science museums, typically lend credence to the value of integrating STEM content into experiences that invite play, tinkering, discovery, and risk. Across the P–12 spectrum, and even in teacher professional development, educators can take greater advantage of and more broadly use physical models or structures to serve as catalysts for learning. Through the selection of materials and the staging of a creative STEM environment, educators help focus and organize the learners' minds on tangible elements and challenges (Nell et al., 2013). Such activities have guidelines and rules, but there is an extent to which the breaking or bending of rules is allowed to encourage experimentation, dabbling, and the trying of new things (Betrus, 2015). Educators may explore alongside the learners and facilitate reflective dialogue to bring richness and clarity, and build understanding, but without direct instruction or interference (Gopnik, 2011; Nell et al., 2015). Examinations of student learning demonstrate that, although direct instruction results in children gaining knowledge, when children also are allowed opportunities to explore the content, they learn additional skills such as creativity and problem solving (Gopnik, 2011).

These types of intentional play activities can help legitimize behaviors that are core to the practice of science and engineering, including "not knowing." Ignorance and not knowing are used as an inspiration for learning and improvement in science and engineering research and development (Camins, 2012). Setbacks, or failures, are viewed as part of the learning progression and are associated with encouragement to try again using a different approach.

STEM 2026 foresees the potential benefits of extending the philosophies and principles of constructing knowledge from experience that occur more typically in early childhood, elementary, and out-of-school and informal learning settings to all stages of the education continuum. As envisioned by the project contributors, the future of STEM education applies the latest approaches used in science fair competitions to integrate intentional play into instruction using physical elements as well as technology. Some science learning centers, schools, and educators are already beginning to use these types of approaches.

Science fairs have a history of providing more accessible and flexible STEM learning spaces for children and students of all ages, as well as families and the broader community. The momentum around science fairs has grown in recent years as the focus on STEM education has increased, and they offer a promising mechanism for engaging and publicly recognizing the innovative ideas and projects youth create when given the opportunity to explore, discover, and invent. In addition, the work of informal learning organizations, like The New York Hall of Science (NYSCI) as just one example, can serve as potential models. NYSCI, among other organizations, have long provided spaces and active encouragement for intentional play that can enhance STEM learning. NYSCI has established an approach to STEM learning in its exhibit designs that it calls Design Make Play. This Design Make Play approach uses strategies to help make "STEM learning irresistible" by engaging participants as creators and encouraging them to develop divergent solutions through guided play. The idea is to foster the scientific imaginations of youth by creating spaces and environments that are inviting and offer "a low barrier to entry, a high ceiling of rich potential complexity, and a wide berth for creative expressions of ideas." For example, a Little Makers exhibit designed for preschool-age children and their families invites children to invent their own citrus-flavored drink and, while doing so, learn the chemistry behind acids in citrus fruits like lemons and limes.

As another example, the NYSCI Design Lab is a 6,300 square foot exhibition space comprising distinct activity areas designed to encourage hands-on, collaborative, problem-solving experiences that introduce learners of all ages to the fundamentals of engineering through design (NYSCI, 2014). Design Lab activities are wide-ranging and rotate on a regular basis. They've included activities where students, Grades 3–12, are invited to work together to build large structures out of 3-foot dowels using rubber bands as connectors; or use index cards, brass fasteners, and wooden sticks to create shadow puppets that move and explore firsthand how light interacts with matter. Design Lab activities are intentionally developed to embed personal relevance and purposefulness in the learning experience and "use everyday materials to emphasize that creativity is not dependent on specialized knowledge. Instead, the activities show how expertise is achieved through experimentation, critical thinking, and collaboration."[11]

One contributor described the larger role advanced technologies today, like computer games, 3-D printers,[12] and similar technologies of the future, can play in developing content knowledge and skills in formal school settings. An increasing number of games, such as Foldit and Minecraft, enable tens of thousands of people, including youth, to tackle major scientific challenges. Foldit, for example, challenges players to fold protein structures in a competitive game environment. Players may be trying to figure out the most efficient way to fold the protein structures while at the same time contributing to the creation of important real-world applications in medicine and molecular biology. Minecraft is an open world game set in an immersive virtual environment. The education edition of the game is designed to promote collaboration, problem-solving, and creativity as students learn through a combination of observation and play-based practice that incorporates opportunities for trial-and-error.

3-D printers, as another example, can provide learning experiences that encourage students to think big with little risk. 3-D printing "failures," for example, serve as an opportunity to rebuild and redesign something even better with little lost in the initial investment. Students can create inexpensive models for inspection and touching, like 3-D-printed replicated dinosaur artifacts and cross-sections of human organs. They also can create a new rocket engine or prosthetic limb without the fear of costly reduplication efforts after an initial failure. One can imagine how this manufacturing tool or others developed in the future could take the concept of shop class to a new level, encouraging the students themselves to be the innovators through tinkering in an economical and timely manner.

Rapid prototyping tools like 3-D printers and emerging software tools like ViZTouch that are being developed and tested through research and development partnerships also can create more accessible and inclusive learning environments for students with limited or no vision, or other disabilities that challenge their ability to access visual representations. These types of tools allow for the creation of a wide array of tactile visualizations and graphics that can be created in just minutes or hours using affordable materials (Kidd, Brown, & Hurst, 2012). In the future, alternate forms of representation that can help bring STEM content to life can be anticipated as new knowledge, experience, and advancements in technology (Kidd et al., 2012).

Students who are engaged in these types of intentional play activities see the relevancy of the content and can begin to perceive themselves as active and successful learners. These less intimidating environments are accessible to all learners, including students with disabilities, ELs, or other youth who have struggled in more traditional classroom settings, to participate in STEM learning communities and graduate to more complex activities at their own pace as they gain experience (U.S. Department of Education, OET, 2016). More specifically, these types of activities help develop growth mindsets rather than fixed mindsets among children and youth. Students with growth mindsets recognize that intelligence and talents are not static but can be developed through perseverance and hard work (Boaler, 2016; Dweck, 2006). This may be especially critical to engaging and retaining historically underrepresented groups in STEM education, given persistent stereotypes and biases about who is good at and belongs in STEM. Neurological research shows that, with adolescents in particular, there exists a "special opportunity to engage them in new and creative ways of being and doing: 'A good learning environment acknowledges that the primary mandate of young people is identify formation, and provides them with opportunities to safely envision themselves as the adults they want to become' " (The XQ Project, 2016, p. 7).

In her book on developing mathematical mindsets in youth, Professor of Mathematics Education at Stanford University, Jo Boaler emphasizes that students' beliefs about themselves are paramount to their learning and their abilities to overcome setbacks and achieve their goals (Boaler, 2016).

STEM 2026 builds off these emerging philosophies and approaches to teaching and learning that invite intentional play and risk. It does so in ways that reimagine the learning spaces and the tools and technologies that facilitate authentic STEM learning experiences for diverse students, including students who often encounter barriers to accessible and appropriate STEM learning experiences like students with disabilities and ELs, as illustrated in more detail in the following sections.

Educational Experiences That Include Interdisciplinary Approaches to Solving "Grand Challenges"

In STEM 2026, integrated STEM teaching and learning experiences are incorporated throughout the P–20 continuum and may occur in school, in an out-of-school program or activity, throughout a curriculum or in a single course, or be reflected in a schoolwide approach to STEM education (National Academies Press, 2014). A predominant feature of integrated and interdisciplinary approaches to STEM education is the use of real-world situations or problems, sometimes coined "grand challenges," as the basis for creating an experience that connects two or more disciplines within STEM, or connects at least one STEM discipline with a non-STEM discipline. In the context of this vision, the project team drew on the Office of Science and Technology Policy's (OSTP) description of 21st Century Grand Challenges. OSTP describes these as "ambitious but achievable goals that harness science, technology, and innovation to solve important national or global problems and that have the potential to capture the public's imagination" (https://www.whitehouse.gov/administration/eop/ostp/grand-challenges, para. 1).

Tasking students with tackling a grand challenge provides them with the opportunity to understand the relevance of STEM to their lives and to see the value of STEM in addressing issues that are important to their communities. Undertaking a grand challenge also gives students an accessible entry point as well as the freedom to tinker with ideas because there is no one right answer to solving these issues. Therefore, actually solving the challenge is not the learning goal. Rather, the *process* of developing the solution through interdisciplinary teamwork and persistence is the objective. (See Text Box 2. Teaching and Learning With Grand Challenges.)

TEXT BOX 2. TEACHING AND LEARNING WITH GRAND CHALLENGES

STEM disciplines will be at the core of tackling the grand challenges facing society: food, water, housing, transportation, information, climate, security, and so on. Tackling these challenges will involve network-based innovation. For example, can students individually or collaboratively play a meaningful role or have agency in being part of effective networks that tackle these challenges? There is a growing body of "big data" concerning these issues that not only needs highly distributed analysis but also can be a fertile playing field for potential global, networked youth STEM programs that build over time and make a real-world impact.

Grand challenges can be introduced to children at any age and in any school, early childhood program, community, afterschool, or informal learning environment. For example, at the preschool level, children can be asked to come up with a "why" question that they work together on with the teacher to solve as co-discoverers.[13] Elementary students may be tasked with designing a mechanism or tool to prevent instances of spilled milk during mealtimes, and upper grade students can be engaged in role-play as a team of engineers and scientists who are working together within a fictional story line to recommend a solution suited to the local environment (American Society for Engineering Education, 2014).

In STEM 2026, the opportunities to engage in interdisciplinary approaches to solve grand challenges like these must be supported through an effective mechanism for ensuring all students' equitable access to high-quality learning experiences. Informal educators and teachers in schools must be equitably and adequately supported with the training and access to the resources that can help them shape instruction and create learning experiences that connect STEM in ways that promote coherence between and among the STEM disciplines and non-STEM disciplines. Indeed, interdisciplinary approaches to teaching and learning that appropriately and effectively integrate and show connections among key concepts and ideas between two or more STEM disciplines or between one or more STEM disciplines and a non-STEM discipline are more nuanced than simply integrating content across traditionally siloed classes. At times, students can benefit from learning a STEM discipline independently. For example, in Algebra, it is important to first gain an understanding of the learning development and progressions that must be attended to in developing students' algebraic foundations and skills before interweaving other related disciplines into the learning activities (National Academies Press, 2014). Relying solely on this approach, however, may limit opportunities for young children to explore scientific concepts in accessible and inclusive ways and may disengage students who struggle to engage with the content until it is situated within a context.

Training experiences for educators in effective strategies for providing integrated STEM education may include collaboration with researchers and STEM professionals, and explicit training in how STEM discipline-specific topics relate to or connect with other STEM and non-STEM disciplines, including art, history, and social studies. As envisioned in STEM 2026, when these types of training opportunities are provided to educators, and when integrated STEM education is implemented appropriately for students, grand challenges can be of great value.

The nation also can build on the work US2020 and the Obama Administration's efforts to increase the involvement and expand access to STEM professionals who serve as volunteers and mentors to support STEM learning, with a particular focus on providing more role models for girls, minorities, and low-income youth in STEM education. These professionals can help bring the type of integrated and context-bound learning experiences to life, both inside and outside of school. The US2020 movement appears to be gaining momentum and growing commitments from cities and organizations across the nation (Kalil, 2013).

Tackling grand challenges also may facilitate "bootstrapping," or the ability to get oneself out of or make sense of a problematic situation using existing resources and knowledge. Students can learn bootstrapping methods by being tasked with solving difficult and complex challenges, often where one right answer isn't yet known or expected. STEM professionals frequently rely on bootstrapping in the process of working collaboratively to develop and test innovative solutions.

Bootstrapping techniques also allow for more accessible and inclusive learning experiences where experimentation and innovation is encouraged in the context of gaining content knowledge and experience. For example, a re-envisioned statistics class at the postsecondary level may involve a group of students fully engaged in a project that challenges them to use their statistical skills to provide guidance to the chief executive officer of a major international corporation. Students are not passive consumers of knowledge in the classroom but, rather, a group of analysts determining the benefits of a proposed international trade agreement. As one contributor to this project described with this scene, these students are energetically discussing potential approaches to analysis and presentation of trade data for particular products as well as how to estimate future trade based on alternative scenarios. Specially trained "learning assistants" are roving around the classroom to provide hints to students and answer questions on potential analytical tools.

This contributor's vision demonstrates how in STEM 2026, students are enabled to learn interdisciplinary concepts together as they also pick up presentation skills and learn how to work in groups. Activities like these make the content relevant and provide authentic workplace environment experiences, further facilitating the transition from school to career.

In another example, two contributors to the vision imagined a theme-based approach to STEM teaching and learning to support the application of STEM knowledge. They envisioned a school where students arrive "ready to actualize the full potential of their entrepreneurial spirit." A mathematics lesson may have students learning how to calculate profit and loss based on the pricing of the products they created in a computing and design class. Or a combined biology and chemistry class lesson may be held in a research lab, with the lesson focusing on hair protein and mitochondrial DNA and why some people have varying curl patterns or straight hair. Lesson activities like these promote student learning in deeper ways that go beyond the mere regurgitation of information.

These sorts of STEM experiences also provide critical opportunities for more culturally relevant teaching and student learning experiences. STEM content, when delivered in a context that sparks students' interest and imagination in relatable ways, leads students to see themselves as empowered in the STEM community. As one contributor shared in her vision for promoting more gender equity in technology development, innovation, and problem-solving: "I dream of a STEM teaching space in which groups of girls, especially girls of color, are learning science and mathematics content not to pass from grade to grade but to enhance or produce commercially new products."

Finally, in designing these types of activities to reach their full potential for inclusive student engagement, special attention must also be paid to ensuring their accessibility to students with disabilities. In 2012, with the support of an NSF Research in Disabilities Education (RDE) program grant, the Center for Assistive Technology and Environmental Access at the Georgia Institute of Technology published a report on accommodating the needs of students with disabilities in STEM education. This publication provides a literature review of the accommodation of STEM learners by functional ability and by specific STEM disciplines, including strategies for using universal design approaches and human- and technology-based approaches to accommodation (Moon, Todd, Morton, & Ivey, 2012).

Flexible and Inclusive Learning Spaces

STEM 2026 also recognizes and aims to capitalize on the opportunity to create more flexible and inclusive learning spaces using flipped classroom approaches and technology-enabled tools if an effective mechanism for ensuring equity of access and use of these methods and tools is established.[14] Flipped classroom approaches to STEM education, where students gain content and technical knowledge through online videos outside of the school day to prepare them for more active, applied learning of the content in the classroom, and other technology advancements can expand students' access to authentic and interdisciplinary STEM learning experiences. Early research on flipped learning suggests students benefit from this approach with respect to improved test scores, course completion rates, and attitudes toward learning (Hamden, McKnight, McKnight, & Arfstrom, 2013). Research also indicates that using technologies like simulation-based games, mobile devices, and virtual environments can facilitate student-centered instruction and support students' retention of information, engagement, skills training, and learning outcomes (Chen, Metcalf, & Tutwiler, 2014; Grotzer et al., 2015; Sitzman, 2011). Some of the emerging technologies to which policymakers, researchers, developers, and educators can turn in crafting the future of STEM education include:

- Online collaboration tools
- Online and hybrid educational environments
- Immersive media
- Games and simulations
- Intelligent tutoring systems[15]
- Augmented and virtual reality

Learning spaces, including flipped learning classrooms, that are supported by online teaching tools and adaptive, embedded technologies, offer teachers and students flexibility in structure, equipment, and access to materials, both in the natural world and virtual and augmented settings. They also can be designed to provide real-time, intelligent feedback cycles that facilitate new modes of learning and collaboration among peers and educators. In recognition of the potential future role technology can play in creating more flexible, accessible, and inclusive learning environments, the Department launched its EdSim Challenge with a call for public feedback in November 2015. As it moves forward, the EdSim Challenge will officially invite gaming, developer, and educational technology communities to design simulated environments that prepare students for a more competitive world through CTE education. Through EdSim, the Department seeks to promote educational simulations that pair next generation technologies with rigorous educational content and integrated assessment.

The PAST Foundation also is drawing on the advantages of technology to expand access to high-quality STEM education, particularly in rural communities. The PAST Foundation's Innovation Lab, which grew out of the work of an international group of anthropologists, field and research scientists, museum curators, and educators, has developed intensive hands-on approaches and consultation to schools to guide their transition to transdisciplinary problem-based STEM learning (TPBL). TPBL is an approach to learning that blends culture and education by drawing on the perspectives of multiple disciplines to explore a relevant problem or issue, thereby connecting new knowledge and understanding of content to real-life experiences. In one PAST Innovation Lab project, the South Dakota Innovation Lab (SDIL), Master TPBL teachers are shared across schools and classrooms in person and virtually. Students from different schools are enrolled in the same course that meets at the same time and is led by a team of teachers located across the school sites. During one class convening, one Master teacher is at one of the schools while the other teachers join the class virtually (see Figure 1). The Master teachers rotate among the classes throughout the duration of the course. This blended, virtual model helps address rural community needs, including key challenges related to resources and geography like lack of expertise and staff on-site or in the immediate community. The hybrid teaching model brings high-quality, innovative STEM education to schools while maximizing budgets (Smith, Schneider, Hunter, & Corbin, 2014).

Tools like these facilitate a learning ecosystem that enables deeper learning in STEM. They can bring the world into the classroom and the classroom to the outside world. Through interactive digital infrastructures, these tools also can promote creative problem solving among students; teacher administrative and course authoring tools; differentiated curriculum content and aligned diagnostic assessments; and supports for classroom monitoring and management.

Figure 1. South Dakota Innovation Lab Hybrid Teaching Model

Source: PAST Innovation Lab

The work of a team at Harvard University illustrates another approach to reimagining the potential that technology holds for creating more flexible and inclusive learning spaces that enhance STEM education. This team has developed a set of tools, EcoMUVE and EcoMOBILE, that combine a curriculum-based virtual learning environment with a complementary augmented reality. EcoMUVE, with guidance from a teacher, engages middle school students in an immersive computer environment designed to teach youth to reason about causal complexity in environmental science, such as fish kill in a pond. EcoMOBILE software extends student learning with its mobile technologies that augment what students observe in the learning setting. For example, using EcoMOBILE technologies, a pair of middle school students may use a handheld tablet connected to a probe to figure out how much dissolved oxygen there is in a pond near their school. Each member of this team of students plays a specific role. One student is the water quality specialist who first learned her role in the classroom and practiced her craft in a virtual pond ecosystem. Another student plays the role of the naturalist who, before the pond experience, used a camera tool and virtual field guide to learn about the organisms in the pond. Together, these students share what they have learned in their different roles, discuss the data they collected, and use their collective knowledge to understand the pond environment.

Research suggests that this combination of simulation and augmented reality is a powerful way to affect learning transfer. Although EcoMUVE and EcoMOBILE are designed to have value as individual tools, the opportunities for enhancing STEM learning may be strengthened when used together. Evidence suggests that EcoMUVE and EcoMOBILE, in tandem, provide a learning environment that is empowering, but, importantly, in the context of what is instantiated and implemented in the school. They have been shown to support teachers' use of difficult pedagogies and instruction of complex content and also promote self-directed learning among students, an important lifelong learning skill.[16]

EcoMUVE and EcoMOBILE are among many education technology tools that exist or are under development. The National Education Technology Plan 2016 (U.S. Department of Education, OET, 2016), provides several examples of technology-enabled education tools that highlight the potential benefits of integrating technology in our education system. Teachers and students are better prepared and equipped to take ownership of their experiences and drive their growth. A contributor explained, "The classroom no longer feels like a classroom for taking courses; it feels like some kind of laboratory or incubator where [students] get to explore, collaborate, and discover at the same time [they] learn about science."

TEXT BOX 3. INTELLIGENT TUTORING SYSTEMS

Intelligent tutoring systems are computer systems that aim to provide immediate and personalized feedback to the learner. They are typically designed to simulate a human tutor's behavior and guidance (Educause Learning Initiative, 2013).

Intelligent tutoring systems may play a key role in the future of education. They are unique from most computer-aided instructional tools on the market in that they are designed to interpret complex student responses and learn as they operate. These systems alter and adjust their own behavior in real time to interact more effectively with a student. These tutoring systems use their interactions with students to build individual student profiles that estimate overall level of mastery but also diagnose the type of errors a student is making and why the student made the errors.

As with all education technology tools, however, the benefits of intelligent tutoring systems will be realized only if they are equitably accessed and effectively integrated into and coordinated with complementary learning activities such as group discussions and project-based learning.

Source: https://net.educause.edu/ir/library/pdf/ELI7098.pdf

Intelligent tutoring systems (see Text Box 3) are another emerging innovation that, when coupled with effective teachers in the classroom, supports the type of self-directed and more flexible and inclusive learning environment that the project contributors envision in STEM 2026. These types of systems help teachers, and potentially families, provide additional opportunities for students to interact with a tutor and receive real-time feedback. With the support of intelligent tutoring systems, well-trained teachers attuned to their students' individual interests and needs in the classroom can ensure learning experiences are immediately adjusted based on each student's learning progression and his or her actions and responses to given questions and lesson activities (Educause Learning Initiative, 2013; U.S. Department of Education, OET, 2016).

Carnegie Mellon University's Cognitive Tutor Software is one example of an existing intelligent tutoring system. Some educators are incorporating this software into their classrooms, and the system is starting to take hold in Grades 9–12 mathematics classrooms across the nation with promising results.[17] A two-year study that examined the effectiveness of Cognitive Tutor blended learning curricula in Algebra I in seven states found that, on average, students who participated in this program nearly doubled the gains of a typical year's worth of learning (Pane, Griffin, McCaffrey, & Karam, 2014). Likewise, an independent study of Carnegie Learning Cognitive Tutor in Miami-Dade County Schools demonstrated significantly better student performance on the state test among students who had access to the software compared with students who did not. The higher performance scores were particularly pronounced among students with disabilities and ELs, including those with learning and behavioral difficulties (Sarkis, 2004).

Other examples of intelligent tutoring systems currently in practice include Arizona State University's Andes Physics Tutor and Writing Pal. Free resources exist as well, including ASSISTments (Educause Learning Initiative, 2013). These types of intelligent tutoring systems remain limited in today's education technology market and in scale of practice, but provide a glimpse into the future.

In moving STEM 2026 forward, planning for these sorts of interactive platforms and the wider use of technology-enabled tools that use big data analytics requires attention to the challenges related to complying with data privacy requirements. The National Education Technology Plan (U.S. Department of Education, OET, 2016) specifically notes that data privacy, including compliance with the Family Educational Rights and Privacy Act (FERPA), is a significant issue to address in the advancement of technology-enabled teaching and learning (U.S. Department of Education, OET, 2016). The plan states, "As students use technology to support their learning, schools are faced with a growing need to protect student privacy continuously while allowing the appropriate use of data to personalize learning, advance research, and visualize student progress for families and teachers" (U.S. Department of Education, OET, 2016, p. 5). The Privacy Technical Assistance Center (PTAC) provides guidance and resources on FERPA that are accessible online, for parents and eligible students and for school officials to support their understanding and compliance.[18]

In addition, there must be focused attention placed on the types of accommodations children, adolescents, and young adults with disabilities will require to equitably participate and benefit from STEM learning experiences that are delivered through technology-based platforms. For example, lab equipment that integrates digital electronics to translate measurements and actions into some form that is accessible to a user based on the user's disability (Moon et al., 2012). There also should be focused attention paid to ensuring technology tools are made more accessible and inclusive to enhance the experiences of rural students, students living in poverty, and ELs.

Indeed, in STEM 2026, the development, adaptation, and use of technology innovations are considered within the context of a robust R&D ecosystem to ensure accessibility, inclusiveness, and effectiveness of tools in particular contexts and to serve diverse learners. To realize the benefits of education technology, educators themselves need to be collaborators in the research and discovery process, with their schools, alongside universities, serving as "incubators of exploration" (U.S. Department of Education, OET, 2016, p. 1). The effective use of technology in education will come from the combination of technology with the human element, where researchers and practitioners work and learn together, "seeking new knowledge, and constantly acquiring new skills alongside their students" (U.S. Department of Education, OET, 2016, p. 1).

In addition, for technology-enabled learning to accelerate, amplify, and expand effective teaching practices, all educators will need the knowledge, skills, and resources to capitalize on the benefits technology-rich learning environments can offer (U.S. Department of Education, OET, 2016). For example in using technology to enhance learning, educators will require additional training in how to "help students access online information, engage in simulations of real-world events, and use technology to document their world, educators can help students create spaces to experiment, iterate, and take intellectual risks with all of the information they need at their fingertips" (U.S. Department of Education, OET, 2016, p. 28). Educators also can be trained to become leaders or active participants of evaluation and implementation of new technologies by designing, piloting, and modeling short studies that impact few students. Although the risks of engaging even a small number of students must be closely assessed first, these instructor-facilitated studies allow schools and organizations to "gain experience with and confidence in these technologies" before committing to a full-scale adoption (U.S. Department of Education, OET, 2016, p. 27).

Outside of school, new research shows that youth and their families can be cross-generational teachers and learners in their own homes and communities. A nationally representative telephone survey of nearly 1,200 parents whose income falls below the national median and who have children ages 6–13 found that 77 percent of parents help their children use digital technology, but it is not a one-way learning environment (Rideout & Katz, 2016). More than half (53 percent) reported that children help their parents, and the majority, that children help each other (81 percent). A greater recognition and understanding of how families serve as digital learning teams can inform policies and practices that can advance the nation toward STEM 2026 (Rideout & Katz, 2016).

Another way to think of flexible and inclusive learning spaces in STEM 2026 is to reimagine where schools themselves are located. In the imaginings of one contributor to this project, the physical boundaries of teaching and learning among youth, educators, and experts in the field are blurred. Schools are better connected with workplace settings. Teaching and learning experiences and learning settings are enhanced as students, teachers, and workplace employees exchange knowledge and ideas in a variety of educational settings. CTE programs already are employing this type of approach. Many CTE programs apply hands-on and lab-based teaching and learning approaches that are designed to provide students with experiences that introduce them to the actual work and practice of STEM in a variety of occupations and job positions. For example, an *IndustryWeek* article offers a few examples of CTE programs that appear to be providing beneficial STEM learning experiences for students:

> [At] Linked Learning schools in California, at the MET schools in Rhode Island, and at Tech Valley High outside Albany, high school students complete internships in real workplaces, exploring fields as diverse as baking, engineering and biotechnology. Students have the opportunity to check out more than one profession so they can see how adults use their education in the workplace. This helps students stay motivated to earn a degree and introduces them to the behaviors and practices specific to the working world. (Nash-Hoff, 2013, para. 3)

Some jurisdictions are building on the CTE model to create STEM pathways that are in direct alignment with in-demand STEM jobs and provide students with hands-on opportunities to explore STEM careers in these growing markets and be prepared to enter them. The Illinois Pathways initiative is one example of a state effort to build local-level public-private education partnerships organized around several industry-specific STEM Learning Exchanges, each of which comprises a network of education partners, businesses, industry associations, labor organizations, and other organizations. Programs of study vary, ranging from Energy to Agriculture, Food, and Natural Resources; Architecture and Construction; Manufacturing; and many others. Students in pathways courses are provided access to work-based learning experiences in the STEM Learning Exchange industry in which they are participating, including activities that develop career awareness, career exploration, career preparation, and on-the-job learning experiences and training.

The time is ripe for rethinking the space of the classroom, including where and with whom STEM learning occurs, the role of work-based learning experiences in offering alternate spaces that can deepen understanding and content-knowledge in STEM, and how rapidly evolving technology can be leveraged to connect and empower students, educators, businesses, and communities in flexible and inclusive learning spaces. Innovative approaches to identifying and creating a wide array of learning settings can create new opportunities for engaging diverse learners in STEM teaching and learning environments that promote interest and cultivate STEM talent.

Innovative and Accessible Measures of Learning

As President Obama has noted, we as a nation need to ensure that the tests students are taking are fair and reduce the amount of classroom time spent on testing. One way to do that is to ensure that there are innovative and accessible measures of learning that allow students to showcase the diversity of their skills and abilities, and allow students to experience a sense of achievement in STEM without being burdensome.

Although it will remain important in the future, as it is today, to assess the extent to which students are equitably developing facility with and mastery of core content knowledge, the future measures of learning, as envisioned by project contributors, also value the enduring skills and personal qualities that demonstrate academic tenacity and competence, and other lifelong learning skills that will remain relevant in 10 to 20 years (Duckworth & Yeager, 2015). The learning measures of the future also take advantage of the latest technologies to enhance Universal Design for Learning (UDL) principles that are implemented in accommodating the needs of students with disabilities.

Technology-enabled assessments, including those that are tailored with embedded accommodation and assistive technology are emerging as potentially powerful mechanisms for measuring growth mindsets or behavioral attributes of students as they engage in the learning process (West, 2011). The ability to better understand the manner in which individual students approach, engage, and persist through the content being taught and associated activities can provide teachers with new insights on how to best support young people's advancement. For example, in the STEM 2026 vision, these types of innovative and accessible measures of learning help pinpoint what educational materials, activities, and learning approaches produce the best results for particular students' learning, and teachers are able to adjust instruction and resource allocation accordingly. They also support real-time measures of learning that can lead to immediate feedback cycles to promote students' engagement and help them learn skills and strategies for persisting through and understanding difficult content (Duckworth & Yeager, 2015). Real-time assessments can help identify meaningful patterns of behavior and could, thus, support educators' ability to adjust and enhance instruction in the moment of student learning—literally as students grapple with and develop understanding of key concepts.

Myriad digital technologies hitting the market or being developed enable innovative and accessible measures of learning that can be collected in real time and result in immediate feedback to the student. Recognition is growing among educators that learning occurs everywhere from the formal classroom to informal settings such as makerspaces, libraries, and museums to more structured out-of-school contexts such as extracurricular programs. Youth are often successful when they draw on their full range of knowledge, gained across a multitude of these types of settings, "yet the skills they learn in one space are rarely acknowledged or valued in others"

(Fontichiaro & Elkordy, 2015). Digital badging is an emerging mechanism for recognizing and rewarding student learning and growth in a wide variety of settings, not just in the formal school system. Students can earn badges by demonstrating declarative knowledge or skill in a content area or through intellectual, social, or behavioral growth that supports their learning trajectories (Fontichiaro & Elkordy, 2015). Digital badging has the potential to better showcase the range of skills, knowledge, talents, and experiences students hold and can contribute to future employers, college and university programs of study, or to other organizations. Digital badges can be valuable tools as the nation moves to an even more digitally connected world, as they exist in cyberspace, so can be housed in a central, virtual gateway, or be advertised in social media profiles, electronic portfolios or resumes and curricula vitae (Fontichiaro & Elkordy, 2015). Although the use of badging is still limited in the education community, some schools and organizations are beginning to experiment with this approach.[19]

Personal response technology, including intelligent tutoring systems as discussed previously, and gaming offer additional examples of emerging, present-day models for real-time measures of learning and feedback cycles that can be integrated into STEM activities (U.S. Department of Education, OET, 2016). As identified in the 2016 National Education Technology Plan, "Games such as Ripple Effects and The Social Express use virtual environments, storytelling, and interactive experiences to assess a student's social skill competencies and provide opportunities to practice" (U.S. Department of Education, OET, 2016, p. 8). In addition, Filament Games developed a suite of learning games, aligned with the UDL principles referenced previously, that are designed to introduce middle school students to scientific concepts using multiple means of representation and provide real-time assistance based on what a student may be struggling with, such as in-game glossaries (U.S. Department of Education, OET, 2016).

With respect to ensuring UDL principles are applied in the design and implementation of these types of innovative approaches to measuring student learning, developers can build on the work of organizations like Nimble Assessment Systems and the Information Research Corporation, both of which are recognized in the Department's 2016 National Education Technology Plan (U.S. Department of Education, OET, 2016). Nimble Tools embeds accommodation tools such as a keyboard with custom keyboard overlays, an on-screen avatar that presents questions in American Sign Language, magnification of text and images, among many others (U.S. Department of Education, OET, 2016). The Information Research Corporation developed eTouchSciences, an integrated software and hardware technology platform that includes devices that provide multiple forms of feedback, including tactic, visual, and audio, to the student (U.S. Department of Education, OET, 2016).

In sum, STEM 2026 envisions a more multifaceted and holistic approach to understanding students' development of the full range of skills that promote STEM educational pathways and lifelong learning. Innovative and accessible measures of student learning provide teachers with the information and tools they need to provide immediate feedback to students that deepen and extend their learning, while also providing students with multiple opportunities to experience improvement and success. There remains a focus on the extent to which all students are reaching certain levels of mastery, but learning progression indicators of students' talent and potential, as demonstrated by having a growth mindset, for example, are emphasized as well.

Societal and Cultural Images and Environments That Promote Diversity in STEM Opportunities and Careers

In STEM 2026, how STEM is messaged to youth and their families is transformed. Popular media consider issues of cultural diversity and identity in portrayals of who does science, what the "doing of science" entails, and who excels in these fields in ways that counter stereotypes and mitigate implicit biases that have historically prevented the full participation of certain groups of individuals. The notion of STEM education is complex and presently, among the broader public, not well understood and typically narrowly defined (Volmert, 2013). In achieving the goals of STEM 2026, it will be important to increase awareness of the implicit biases inherent in educational policies, practices, structures, that adversely influence the accessibility and inclusiveness of high-quality STEM teaching and learning experiences for all students (Handelsman & Sakraney, 2015). Actively engaging popular and mass media outlets, and other key players who influence the way STEM is messaged more broadly through toys and games that target young people, and in informal and formal learning settings can play a critical and potentially effective role. The results of studies on implicit bias, and the results of past mass media campaigns intended to influence people's attitudes and behaviors, shows that exposing people to counterstereotypes can reduce the application of implicit biases and change public perceptions (Handelsman & Sakraney, 2015). Repeated exposure through STEM-themed media that is designed with any eye toward mitigating or reversing common implicit biases in STEM, can help deepen understanding of the immediacy and relevancy of STEM in all people's lives and communities (Traphagen & Traill, 2014; Volmert, 2013).

One way that popular media and toy retail outlets, including movies and films, television, and social media, can be engaged to promote more inclusive STEM images and environments is by including a greater diversity of developers and producers in leadership and creative positions (Bunche Center, University of California Los Angeles, 2014; Smith et al., 2014). Data continually demonstrate that the landscape of popular media, including popular cinema, "remains skewed and stereotypical" with respect to gender, sexual, and racial and ethnic portrayals (Smith et al., 2014, p. 21). Persons with disabilities and those from low-income families also are largely not included in cultural and societal perceptions of where STEM talent resides, with little recognition of the potential STEM-related strengths, experiences, and knowledge that these families and youth might bring to the equation (Brown, 2016; Rideout & Katz, 2016).

Popular media representations of STEM-motivated characters and themes in shows and films that target young and adolescent audiences also are problematic. For example, although the animated film audience has become increasingly diverse over the years, in 2014, films that include underrepresented characters engaged in STEM activities or professions remain limited (Smith et al., 2014). This lack of vision is particularly notable given that young children are still forming their understanding of their role and place in society, and the stories that drive animated films have such high potential for promoting positive and relevant images of diversity in STEM. In addition, there are very few characters on television generally that openly identify as being disabled, let alone in STEM-themed narratives. When disabled persons are portrayed at all, they are typically white males that are largely defined by their disability and "fueled by stereotypes of 'overcoming' their disability" (Brown, 2016, para. 4).

In propelling the STEM 2026 vision forward, concerted attention will need to be paid to make popular media and retail a vehicle for encouraging and ensuring inclusion, not a perpetuator of inequity. The project contributors imagined media and toy developers and retailers working hand-in-hand with learning scientists to present cultural signals and images that have "changed the face of STEM" to include all members of society, including students of color, ELs, students with disabilities, girls and boys, and individuals from all rural, suburban, and urban neighborhoods. These images encourage all neighborhoods, students, and educators to develop STEM identities and affinities with STEM academic and professional communities.

Fortunately, concerted efforts are being made to promote partnerships like these. The Obama Administration has placed a priority on promoting the inclusion of more diverse and compelling STEM images, stories, toys, and positive messages in entertainment media and retail, and has published a resource, STEM Depiction Opportunities, with this goal in mind. In complementary efforts, the White House convened a day-long conference that brought together and resulted in multiple commitments from toy, media, and retail companies; leaders of youth-serving organizations; parents; researchers; and advocates to develop strategies for breaking down stereotypes in toys and media (The White House, Office of the Press Secretary, 2016). And, in 2014, the White House launched a series, Untold Stories of Women in STEM, to highlight the significant, but often unknown, contributions of women, including women of color, in the history of science and technology.

Other promising efforts include partnerships like the one between the Disney team of creators for the animated film *Miles From Tomorrowland* and technology and science and engineering experts from Google and NASA. Disney engaged these experts to help them authentically portray the key characters, many of whom were women and girls (Wu, 2015). The National Academy of Sciences Science and Entertainment Exchange (the Exchange) is promoting more partnerships like these by providing entertainment industry professionals with quick and easy access to experts from all of the scientific disciplines. The Exchange has facilitated nearly 1,000 consults, including partnerships that were formed in the development of films such as *Big Hero 6, The Amazing Spiderman,* and shows including *The Big Bang Theory,* among others.[20]

In addition, Sesame Workshop has made strides in this arena through its specific STEM initiatives, including Little Discoverers: Big Fun with Science, Math and More. *Little Discoverers* is a digital destination that features STEM-focused games, videos, and hands-on activities that encourage children and families to investigate and explore scientific concepts. These tools also are designed to support early childhood educators in the classroom as they integrate STEM content and concepts into their instruction. Demonstrating to students at these early ages that they are STEM learners and doers not only helps develop children's STEM vocabulary and understanding of challenging concepts but also may help develop their early identities as scientists as they personally experience doing the work of scientific discovery.

Media, including multiplatform media like apps and games, digital media, and social media outlets like YouTube and Twitter, among many others, can play a critical role in countering implicit biases that have historically affected diverse participation and success in STEM education and career pathways by reshaping and developing children's beliefs about how they can understand and shape the world through the STEM disciplines. As one contributor to this project remarked, far more so than in the past, researchers, learning scientists, and media makers can work together to create stories that enable all youth and communities to visualize possible futures in STEM, inspire them to create these futures in real life, and facilitate the pathways for doing so.

Summing Up the STEM 2026 Vision

In STEM 2026, all members of the community feel invested and empowered to engage in STEM teaching and learning. STEM is not perceived as being thrust upon them or outside their purview but as culturally appealing and relevant. The language and concepts of STEM are accessible to all, and there is a shared understanding of where STEM fits into all people's lives, regardless of race or ethnicity, disability, language spoken, gender, neighborhood, or geographic location. The components of the vision and the propagation of innovative practices effectively connect STEM to the broader portfolios of people's interests and their everyday lives. The result is intergenerational learning that empowers learners of all ages to draw on the skills and capacities they have gained as they actively contribute to bettering their own and others' lives.

[8] Under federal disability anti-discrimination law, entities are obligated to provide an equal opportunity to individuals with disabilities to participate in, and receive the benefits of, the educational program. Entities are obligated to provide accommodations or modifications when necessary to ensure equal treatment. Under Section 504 of the Rehabilitation Act of 1973 (Section 504), 29 U.S.C. § 794, these legal standards apply to entities that receive federal financial assistance, including elementary, secondary, and postsecondary institutions. Under Title II of the Americans with Disabilities Act (ADA) of 1990 (Title II), 42 U.S.C. §§ 12131-12134, these obligations apply to entities of state and local government, including public schools. This means that students must be afforded the opportunity to acquire the same information, engage in the same interactions, and enjoy the same services as students without disabilities. One path to equal opportunity is to provide access to technology with universal design principles (i.e., technology that has been designed to reduce barriers for use among persons with disabilities or others who have limitations because of age, ability, or situation and include principles of equitable use, flexibility in use, simple and intuitive use, perceptible information, tolerance for error, low physical effort, and size and space for approach and use [see www.universaldesign.com]). The Individuals with Disabilities Education Act (IDEA), 20 U.S.C. 1400 et seq. also includes specific provisions regarding the needs of eligible children with disabilities for assistive technology, and IDEA Part B funds may be used to provide assistive technology devices and services when required for an eligible child with a disability to receive a free appropriate public education (see IDEA, 20 U.S.C. 1411-1414).

[9] See, for example, the references listed in *Implicit Bias* (Handelsman & Sakraney, 2015) available at https://www.whitehouse.gov/sites/default/files/microsites/ostp/bias_9-14-15_final.pdf

[10] https://www.nsf.gov/funding/pgm_summ.jsp?pims_id=5463

[11] See http://nysci.org/designlab/

[12] For current research, see, for example, Thornburg, D., Thornburg, N., & Armstrong, S. (2014). *Invent to learn guide to 3D printing in the classroom: Recipes for success.* Los Angeles, CA: Constructing Modern Knowledge Press.

[13] See, for example: http://toosmall.org/community/body/STEM-Tipsheet-Families.pdf

[14] See, for example, policy documents issued by OCR regarding the obligations of covered entities to ensure that students with disabilities have equal access to emerging technology. These documents include the June 29, 2010, Dear Colleague Letter issued by the OCR and the Department of Justice to college and university presidents regarding electronic book readers, available at: http://www2.ed.gov/about/offices/list/ocr/letters/colleague-20100629.html; and the May 26, 2011, Frequently Asked Questions about the June 29, 2010, Dear Colleague Letter, which address the use of electronic book readers and other emerging technologies, available at: http://www2.ed.gov/about/offices/list/ocr/docs/dcl-ebook-faq-201105.html.

[15] An intelligent tutoring system is a computer system that aims to provide immediate individualized instruction or feedback to a learner. Typically, intelligent tutoring systems operate without intervention or input from a human teacher.

[16] See a list of publications on EcoMUVE and EcoMOBILE here: http://ecolearn.gse.harvard.edu/publications.php.

[17] For more information on Carnegie Mellon's Cognitive Tutor software and blended learning curricula, including where the software is being used and with what effect, see https://www.carnegielearning.com/.

[18] See, for example: http://ptac.ed.gov/sites/default/files/Student%20Privacy%20and%20Online%20Educational%20Services%20%28February%202014%29.pdf

[19] A list of some of the schools and organizations that are issuing Open Badges for students is available at: http://openbadges.org/participating-issuers/

[20] Additional information and listings of the films and shows that were supported by The Exchange are available here: http://www.scienceandentertainmentexchange.org/projects.

Achieving the Vision

Existing Challenges and Opportunities

The realization of a new future of STEM education will require the involvement and collaboration of multiple stakeholders. The process will entail the development of CoP that invite the input of a diverse group of policymakers, funders, philanthropic organizations, nonprofits, researchers, practitioners, and community leaders in the development and ongoing refinement of a local vision for STEM education. Working together, within their local contexts, these stakeholders must come together to identify their goal for transforming STEM education; where there are biases in the system that differentially affect student participation and pathways, and local strengths that are key leverage points in meeting the diversity of their student's needs. This section presents the challenges and opportunities that present themselves in achieving STEM 2026.

Challenge 1: Promoting equitable access to the STEM teaching and learning experiences envisioned in STEM 2026. In addition to revamping public notions of which groups of individuals and communities belong in STEM, promoting equitable access to the everyday teaching and learning experiences that open the doors to STEM pathways is a long-standing challenge the nation faces. Students who attend high-poverty schools frequently do not have access to experienced teachers in the core subjects of science and mathematics, and many do not even have access to the courses that could put them on postsecondary and career pathways in STEM. In addition, a digital divide remains prominent in the United States. These disparities in access to foundational courses in STEM, out-of-school STEM learning programs, and to technology tools that can enhance STEM learning, hinder the engagement of a diversity of talent that essentially remains hidden among the nation's youth.

According to a report on the 2012 National Survey of Science and Mathematics Education, schools with the highest proportions of students from low-income households are more likely than other schools to have science and mathematics teachers with just one to two years of experience (Banilower et al., 2013). In addition, only 66 percent of schools with the highest percentages of African-American and Latino students are offered chemistry, compared with 78 percent of schools with the lowest percentages of African American and Latinos in 2014. For Algebra II, the percentages were 74 percent and 83 percent, respectively (U.S. Department of Education, OCR, 2014). Moreover, detailed race and gender information by state on 2015 Computer Science Advanced Placement (AP) exam participation rates[21] reveal stark divides among and across states. For example, girls represented just 22 percent of the approximately 50,000 high school students nationally who took the Computer Science AP exam in 2015, and students of color represented only 13 percent.

Substantial disparities also exist between affluent and low-income families and between rural and more urban communities in terms of both Internet use and quality of access (Council of Economic Advisors, 2015). Internet use in families with low household incomes (i.e., between $20,000 and $60,000) ranges from approximately 30 percent to less than 60 percent, compared with more than 80 percent to nearly 100 percent in families at the upper end of the income spectrum (i.e., household income of at least $140,000) (Council of Economic Advisors, 2015). Rural communities, including those in the rural South and the tribal and Indian lands in the Southwest, also demonstrate some of the nation's lowest rates of Internet use (Council of Economic Advisors, 2015). Among these same populations, a new digital divide also has emerged, resulting in notable inequities between "students who use technology to create, design, build, explore, and collaborate and those who simply use technology to consume media passively," with the educational benefits of technology use reserved for students in the former group (U.S. Department of Education, 2015, p. 14; Warschauer, 2012). Finally, disparities in access and participation exist in the afterschool space as well, particularly between rural, urban, and suburban locations, with urban locations having the highest frequency of STEM-focused offerings (Afterschool Alliance, 2014). Afterschool programs that serve higher income students also have more STEM activities than programs that primarily serve low-income youth (Afterschool Alliance, 2014).

These data are concerning because they reveal the extent to which already underserved student populations have limited exposure to the STEM subjects, skills, and technology tools that are increasingly required of all citizens in a more globally connected and technology-driven world. Nevertheless, efforts are underway to bridge the STEM education divide. The education component of the Joining Forces initiative is facilitating partnerships that help ensure the children of military service members are provided with high-quality STEM education. The Joining Forces partnership with the National Math and Science Initiative (NMSI) extends NMSI's College Readiness program to 200 military-connected schools, which includes a specific focus on broadening student access to rigorous AP coursework in mathematics and science and preparing students for the STEM-intensive careers of today and the future (Garg & Lyons, 2016).

Also, state initiatives that mandate computer science education and elevate this subject from an elective to a credit-bearing course are cropping up around the nation. In fall 2015, New York City's Mayor Bill de Blasio announced a 10-year, $81 million dollar plan that will require every public school in the district to offer computer science (Taylor & Miller, 2015). In February 2016, the Chicago Board of Education unanimously approved computer science as a graduation requirement for all Chicago Public Schools students beginning with the class of 2020 (Chicago Public Schools, 2016). Also in February 2016, Governors Asa Hutchinson of Arkansas, Jay Inslee of Washington, and Gina Raimondo of Rhode Island formed the Governors' Partnership for K–12 Computer Science. This bipartisan initiative aims to enable all high schools in their states to offer at least one rigorous computer science course, fund professional training for teachers, and set K–12 computer science standards to guide states, districts, and schools with licensure, curriculum, and graduation requirements—all critical to ensuring equitable access.

More state and local initiatives like these may be anticipated with the inclusion of computer science in ESSA's list of subjects that provide a "well-rounded education," which is supported by the law's authorization of the Title IV, Part A, Student Support and Academic Enrichment grant program (ESSA, 2015, Section 8002). With ESSA, access to engineering courses may increase as well since engineering also is included in the list of education subjects included in its definition of a well-rounded education (ESSA, 2015, Section 8002; Washington Partners, 2015).

To counteract shortages of high-quality STEM instructors, many states also have stepped up their training of prospective STEM teachers. According to the Community for Advancing Discovery Research in Education (CADRE) at the Education Development Center, "A growing number of states are redesigning teacher preparation programs to require more science and mathematics instruction, particularly to build content knowledge and inquiry skills" (CADRE, n.d., p. 2). CADRE also notes that many states are making an effort to provide prospective teachers with early opportunities to gain practical experience in public schools (CADRE, n.d.). For example, California's CalTeach program offers special coursework and field experiences in K–12 schools to undergraduate mathematics and science majors with an expressed interest in pursuing teaching careers. Data show that the program is meeting its goals to increase the diversity of prospective educators in STEM. The majority of CalTeach graduates are racial or ethnic minorities, and nearly 60 percent are women. Over 42 percent are first-generation college graduates. In addition, many of the CalTeach graduates who pursue careers in public schools do so in high-need communities.[22]

100Kin10 is another major effort to increase the number of STEM teachers, with a goal of adding 100,000 STEM teachers by 2021 through training and retraining. The organization draws on the expertise and resources of academic institutions, nonprofits, foundations, companies, and government and state and local education agencies that make a commitment to contribute to the 100Kin10 goal. To date, more than 230 partners have made commitments to recruit, train, and support the development and growth of excellent STEM teachers. The partners are varied and include companies like Battelle and Chevron; national and state teacher associations; districts like Baltimore City Public Schools and Charlotte-Mecklenburg Schools; institutions of higher education like Kansas State University; teacher preparation and training programs like Jackson Teacher Residency and Bank Street College of Education; and numerous museums, informal learning providers, and foundations. Key to its strategic plan is to facilitate opportunities for the partners to collectively address shared problems. One way 100Kin10 facilitates these opportunities is through a Solution Lab, where partners come together to co-create and co-fund initiatives to solve specific challenges such as STEM teacher recruitment and change management for college- and career-ready standards.

Some teacher support for computer science education also is already in place. The CS10K Community offers professional learning to a large virtual network of educators. The Computer Science Teachers Association (CSTA) has cross-walked its K–12 computer science standards against the Common Core requirements.[23] President Obama's Computer Science for All initiative encourages additional national, state, and local efforts to "empower all American students from kindergarten through high school to learn computer science and be equipped with the computational thinking skills they need to be creators in the digital economy, not just consumers, and to be active citizens in our technology-driven world" (Smith, 2016, para. 1). In addition, ESSA includes language about STEM teacher professional development, including differential pay and alternate certification routes for STEM teachers, particularly in high-need and rural schools (ESSA, 2015, Section 2245).

The ConnectED and Future Ready initiatives, and the Department's 2016 National Education Technology Plan (U.S. Department of Education, OET, 2016) outline strategies and actions for closing the digital divide and promoting greater equity in the effective use of technology to enable learning pathways for all students. ConnectED, which launched in spring 2013, leverages federal funds and commitments from organizations like the Federal Communications Commission (FCC), and companies like Apple, Microsoft, Spring, and Verizon to support and help connect all of America's students to next-generation broad-band and high-speed wireless in their schools and libraries. Future Ready recently celebrated its one-year anniversary and has made progress toward its goal of propagating a culture of digital learning in districts nationwide. Since its launch in 2014, the initiative has announced 17 formal statewide Future Ready initiatives,[24] and more than 2,200 district superintendents have signed the pledge indicating their commitment to the goal (Washington Partners, 2015). The 2016 National Education Technology Plan (U.S. Department of Education, OET, 2016) has at its core a focus on ensuring equity of access to technology-enabled education that effectively transforms students' learning experiences. This plan can serve as a valuable resource in monitoring progress and developing strategies for eliminating disparities in when and how technology is used to enhance learning.

With respect to promoting broadened participation and diversity in STEM, the Institute of Education Sciences (IES) What Works Clearinghouse Practice Guide, *Encouraging Girls in Math and Science* (Halpern et al., 2007), includes specific recommendations for teachers to promote engagement and achievement in mathematics and science courses for all students, including girls. The Department's OCR and Office of Career, Technical, and Adult Education (OCTAE) also recently released a Dear Colleague Letter on Gender Equity in Career and Technical Education. This letter makes clear to make clear that all students, regardless of their sex or gender, should be afforded equal access to the full range of CTE programs offered and to announce that OCTAE will release resources that outline promising practices for expanding recruitment and outreach efforts, building staff capacity and knowledge of equity issues, partnering with families to mitigate perceptions of CTE fields that might impact program participation, and using data to monitor recruitment, enrollment, and persistence trends.

In addition, US2020, as mentioned earlier, is designed to increase underrepresented students' exposure to and interest in STEM fields. US2020 aims to match local districts and programs with STEM professionals who can serve as student mentors and facilitate hands-on STEM learning experiences. Computer science advocates Jane Margolis and Andreas Stefik, two of the named White House Champions of Change, and Million Women Mentors are similarly focused in their work. In 2012, the White House honored 14 individuals as Champions of Change for leading the fields of STEM for people with disabilities in education and employment. The work of these individuals included making science museum exhibits more inclusive, developing innovative ways for students with disabilities to develop career skills, developing programs such as a summer Chemistry Camp for blind students, and technologies to enable learning for all (National Science Foundation, 2012). The Champions of Change campaign also includes parent champions, who are making an impact in their community through their involvement in education and their commitments to providing high-quality learning environments in their children's classrooms. Moving forward, parent champions who specifically focus on helping provide accessible, culturally relevant, and inclusive STEM learning experiences can be identified, publicly recognized, and encouraged to continue and grow their efforts.

Working in collaboration with a diverse set of partners, including companies, nonprofits, and individuals, the Million Women Mentors initiative, for example, supports the engagement of one million STEM mentors, male and female, with the intent of increasing the interest and confidence of girls and women to pursue and succeed in STEM programs and careers. Businesses also can play a key role in expanding youth's access to role models and mentors. As just one example, Google gifted office space inside its New York City building to Black Girls CODE, an organization devoted to growing the number of women of color in technology by introducing young girls from underrepresented communities to programming languages and computer coding lessons. Having office space inside Google's building has the potential to give Black Girls CODE participants opportunities to regularly interact with Google employees, develop mentor relationships, and deepen their understanding of the types of STEM careers available to them (Dickey, 2016).

Efforts are underway to promote access to afterschool and informal STEM programming as well. Recent data show that nearly 70 percent of afterschool programs offer STEM learning opportunities (Washington Partners, 2015); and with the support of organizations like the Afterschool Alliance, the STEM Education Coalition, the National Park Service (NPS), and the PAST Foundation, STEM-focused and culturally relevant afterschool and informal learning opportunities for youth are continuing to grow. For example, the NPS Teaching with Historic Places has developed more than 150 classroom-ready lesson plans that are available online and searchable according to location, topic, primary source, and skill. Each of the lesson plans use historic sites as a culturally grounded means for exploring the content and developing new skills, such as design and building and graphic design, in the context of American history. Most students, including those in rural, suburban, and urban communities, live in proximity to national parks, historic landscapes, or historic places, and these sites provide accessible, relevant connections to students' lives and the communities in which they live. For example, middle school students in Massachusetts may visit the Boott Cotton Mills of Lowell and then be tasked with building a mill. Activities include compiling a list of the basic things necessary to build a mill, speculating how a four- or five-story mill would have been constructed, and building a three-dimensional model.[25] Or, students with access to the Dayton Aviation Heritage National Historic Park, home of the Wright Brothers, are guided to think creatively to develop their own interventions with detailed drawings or models.[26]

Also, such nonprofits as Girls Who Code, CompuGirls, and TECHNOLOchicas are providing computer science learning opportunities for young women. Each of these programs and others like them can serve as models from which lessons can be learned and best practices identified about how to effectively connect STEM with culture and authentically situate scientific content.

As a final example, For Inspiration and Recognition of Science and Technology (FIRST) also is gaining substantial ground in making robotics an official sport in some states. Connecticut, Minnesota, and Texas are among a growing number of states that have sanctioned robotics as a varsity letter sport (Kamen, 2016). This designation is important. By becoming an official sport, FIRST provides every student with access to hands-on engineering challenges, places the same honor and recognition on robotics team members as other athletes in a school (Kamen, 2016), and also allows the use of funds to cover teacher stipends. Initiatives like these help broaden the reach of innovative STEM programs, mentors, and role models that can motivate youth to pursue STEM opportunities in communities that would otherwise have limited access and exposure to STEM professionals.

Challenge 2: Propagating engaged and networked communities of practice. Presently, all students do not have access to a networked community that provides early and frequent exposure to STEM. This is a key challenge to achieving the engaged and networked CoP upon which so much of STEM 2026 relies.

Overcoming this challenge will require establishing and propagating local networks of STEM learning and CoP that are grounded in the unique contexts and needs of local communities and that facilitate collaborative and continuous learning about what works best. Many initiatives currently underway hold great promise in this effort.

One example of a promising national initiative promoting this type of work is the STEM Ecosystems Initiative, supported by the STEM Funders Network. The goal of the initiative is to nurture and spread effective STEM learning opportunities for all youth through a national community of practice composed of local networks that work together to create an engaged community of STEM teaching and learning. These local networks are supported with coaching and guidance from recognized leaders in education, science, industry, and other sectors.

One example of a project that has demonstrated success through a community-networked approach is the OC STEM Initiative in Orange County, California. A key objective of the initiative is to "create effective partnerships between community stakeholders, including but not limited to families, businesses, government, and philanthropic organizations" (OC STEM Initiative, 2015, Objectives section). The purpose of these partnerships is to promote STEM competencies across the educational continuum from prekindergarten through college to prepare the county's “children and future workforce to meet the dynamic requirements of a rapidly changing world” (OC STEM Initiative, 2015, Objectives section) and, in turn, foster Orange County’s economic competitiveness and sustainability.

United Way also has a history of collaborating with multiple nonprofit, corporate, and community partners to identify and invest in effective programs that transform impoverished communities into safe and thriving neighborhoods where adults and children have access to good schools, effective health care systems, and livable-wage jobs. Several state and city United Way programs across the nation have a specific focus on STEM, including the Boston, Massachusetts; Broward County, Florida; Dallas, Texas; Orange County, California; and Rhode Island, among many others. As just one example, in Broward County, the Museum of Discovery and Science, in partnership with United Way, launched a two-year high school internship that allows students to explore coding, app development, and careers in scientific fields (Unite Broward, 2014).

Challenge 3: Redesigning lesson activities to promote intentional play and risk. The notion of “failure” often holds great negative power in our education system. This fear of failure among students and teachers is perpetuated by the consequences associated with an incorrect response or a failing grade in today’s system. The problem-solving process, including students’ facility with flexibly applying the knowledge they have gained to unfamiliar or difficult concepts, is typically valued less than mastery. As a result, most children quickly learn to fear and avoid failure, particularly in the classroom. Yet in enhancing STEM learning and developing STEM knowledge and skills, “this inherent intolerance of failure is holding us back from achieving our true innovation potential” (Flanagan, n.d., para. 4).

In the “real world” of STEM, the notion that failure is always bad is impractical and makes little sense. In the research lab, for example, there is a great opportunity to enhance learning through setbacks and failed attempts, an idea that was emphasized repeatedly during our workshop discussions. It is through failure that new questions are posed and new investigations initiated to determine why a technique, structure, or innovation did not work. In a child’s education, allowing for failure can thus provide students with valuable opportunities to engage in problem-based learning, to revisit what is familiar and what is unknown, and to take risks in mapping out new approaches to solving complex problems.

The current student-level maker movement that is sweeping the country, at local, regional, and national levels offers a promising approach and mechanisms for building student interest and engagement in STEM in all communities. Maker events are designed to inspire entrepreneurial spirit among all individuals by democratizing the tools and skills necessary to design and make almost anything. More specifically, underpinning the maker movement is a drive to allow individuals, including youth, to be the creators and change-makers in their communities by giving them the access to the tools, knowledge, and financial means to educate, innovate, and invent using technology and digital fabrication. According to many educators, the maker movement demonstrates that “playfulness and ingenuity can fuel STEM learning” in education contexts (Bevan, Petrich, & Wilkinson, 2014/2015, p. 28). Makerspaces provide an innovative approach to engaging youth from all backgrounds, cultures, and characteristics by celebrating “creativity, innovation, and entrepreneurship through the design and construction of physical objects” (Bevan et al., 2014/2015, p. 28).

In recognition of the promise maker events hold for improving student participation and active engagement in the STEM disciplines, the White House hosted its first White House Maker Faire for students in 2014, and has continued to promote the maker movement through its Nation of Makers website and the now annual National Week of Making. The Department’s CTE Makeover

Challenge also is helping drive the movement forward and promote equitable access to innovative, multifunctional (meaning accessible to and inclusive of all students, including students with disabilities), and sustainable makerspaces by calling on high schools to design makerspaces that strengthen 21st century career and technical skills. Schools serving high proportions of students enrolled in free and reduced-price lunch that submitted applications were eligible to receive bonus points on their submissions.

There also are several examples of maker movement initiatives at the local level. Bevan et al. (2014/2015) highlight a number of these efforts in their article *Tinkering Is Serious Play*. A couple of the examples they discuss are the Tinkering Studio in the Exploratorium in San Francisco, California; and, in a more formal school setting, the Lighthouse Community Charter School in Oakland, California. The Lighthouse Community Charter School has a "Creativity Lab" that supports the integration of making into the classroom. Makerspaces are a core focus of the school's program and its efforts to approach teaching and learning with a growth mindset and to develop students' sense of ownership in their learning. As the authors note in their article, several schools across the nation also are beginning to introduce makerspaces into their STEM curriculum. In some schools, even preschool children are invited to engage in fabrication activities that familiarize learners with new tools and properties of materials through exploration, and then provide more structured tinkering activities that encourage playfulness and creativity around solving a specific problem (Bevan et al., 2014/2015).

Reassessing the value of failure in the learning process and how to effectively invite intentional play into education contexts challenges not just existing perceptions of how to teach STEM content or skills, but how teachers are prepared to structure their classrooms, design learning activities, and provide intervention. Achieving STEM 2026 will require a framework for preparing teachers for STEM teaching and learning that encourages creativity, allows for tinkering, and values student misperceptions. More specifically, teachers need preparation and ongoing support to strengthen their abilities to effectively assess student perceptions of scientific phenomena and explore and expand upon student perceptions, not dismiss them as incorrect (Kesidou & Koppal, 2004; McPherson, 2014).

Some work is already being done in this area. The Tinkering Studio in the Exploratorium has developed a framework[27] for tinkering that outlines key learning dimensions and the associated learning indicators that should be observed during tinkering activities. Frameworks like these can help lay the foundation for more research- and evidence-based models and guides for developing educators' capacity to effectively integrate maker activities into their courses or informal or after school programs.

Recognizing the challenges associated with inviting more playfulness and tolerance for setbacks in STEM teaching and learning, STEM 2026 re-envisions the design of learning activities as purposeful yet encouraging of playfulness as students engage in hands-on experiences to learn new concepts and content. Although the correct or well-reasoned answer or solution remains important, STEM 2026 envisions focus on the process of getting to the answer, as this is critical for developing and measuring student understanding. Reversing the notions of failure and the implications associated with it will open transformative opportunities in STEM for all students.

Challenge 4: Starting STEM education early. The body of scholarly literature and research on early STEM learning experiences is slim and mainly focuses on mathematics (Shilling, 2015). Yet, this lack of evidence-based programs cannot detract from urgency with which the nation must proceed in providing equitable access to early exposure and engagement in STEM learning experiences. The Administration and the Department have recognized this need, and work is underway within the Department to identify developmentally appropriate best practices in STEM early learning. In December 2014, President Obama convened state and local policymakers, mayors, school superintendents, corporate and community leaders, and advocates for the White House Summit on Early Education to promote broad-based commitment to improve access to high-quality preschool and early learning. This summit built off other efforts at the federal level to promote early learning through grants and other initiatives. The Department's Ready to Learn Television (RTL) grant program supports the development of educational television and digital media for preschool and early elementary children. The intent of the program is to promote equitable access to high-quality shows and applications to help develop children's early learning and school readiness, particularly in literacy, mathematics, and science. Since its launch in 2010, five grantees, with national and statewide audiences have been awarded funds ranging from approximately $30 to $100 million dollars over five years. Several independent studies and efficacy evaluations of these first five grantee's RTL programs have been published and collected in a compendium, *RTL 2010-2015: Major Research Studies,* and this document is available on the Department's website.[28]

In a related effort, the Department's Let's Talk, Read, and Sing About STEM toolkit includes tip sheets for families, preschool teachers and providers, and infant/toddler teachers and providers in both English and Spanish. These tip sheets provide resources and recommendations on easy ways to incorporate STEM concepts and vocabulary into everyday routines as well as suggestions for engaging young children in STEM learning activities.

In addition, the Department has focused some federal grant funds on supporting state and local efforts to develop and expand preschool and early learning systems for young children. The Department's Institute of Education Sciences (IES) has invested in early STEM research by funding the development and evaluation of interventions targeting children's STEM skills; measures to assess domain-specific skills such as children's knowledge and understanding of mathematics and science concepts and processes; and professional development interventions to train early childhood educators to implement mathematics and science curricula in preschool classrooms to support children's school readiness skills. The Department's Race to the Top–Early Learning Challenge (RTT–ELC) grants, jointly administered with the U.S. Department of Health & Human Services (HHS), offers another example of the movement to provide greater access to high-quality early learning programs. Specifically, the RTT–ELC grants support states' efforts to improve the quality of early learning and development and close the educational gaps through the design and implementation of an integrated system of high-quality early learning programs and services that results in increased participation of low-income and disadvantaged children and ensures that any use of assessments conforms with National Research Council recommendations.

The Department and HHS also jointly administer the Preschool Development Grant (PDG) program. The PDG program supports both states with either small or no state preschool programs to develop or enhance their infrastructure for preschool programs and states that have a more robust preschool program or have been awarded an RTT–ELC grant to implement and sustain high-quality preschool programs that serve eligible children in high-need communities.

Outside of the federal agencies, the Institute for Early Learning Through the Arts program out of Wolf Trap uses art-based curriculum to enhance student learning in STEM at an early age. A study of the program in one district demonstrated that arts-integrated strategies have significant positive effects on children's learning (Ludwig & Song, 2015). Museums like the Pittsburgh Children's Museum, Boston Museum of Science, and the New York Hall of Science also provide young children with hands-on learning experiences on topics such as engineering and computer science that can complement formal in-school classroom experiences. The Boston Museum of Science also provides pedagogical resources[29] for teachers who visit with their students to help them implement STEM learning in the classroom and build not only their children's knowledge but also their own.

Projects like these provide ripe opportunities for research investment and for lessons to be learned and best practices propagated in propelling the nation toward achieving STEM 2026. Key stakeholders in advancing this movement also can build off the work that has already been done in the area of mathematics to inform the broader STEM content landscape. Although more research is needed, the IES What Works Clearinghouse practice guide, *Teaching Math to Young Children* (Frye et al., 2013), is a useful resource for educators of students aged 3 to 6. This practice guide provides guidelines for teaching and integrating mathematics instruction throughout the school day.

Challenge 5: Reducing stovepipes between STEM topics (and non-STEM topics). Research suggests that "interdisciplinary learning can foster an understanding of STEM concepts in their application to real-world problems, problems that by their very nature are interdisciplinary" (Asghar, Ellington, Rice, Johnson, & Prime, 2012, p. 86). In the field, scientific and technological innovations are not developed in a discipline-specific vacuum but instead by an interdisciplinary team-based approach to solving local, national, and global challenges. Therefore, to better reflect the way existing knowledge is applied and new knowledge is gained in the real world, STEM 2026 teaching and learning experiences that integrate interdisciplinary opportunities for learning are incorporated into the P–12 curriculum.

Some schools and districts also are already reinventing approaches to STEM teaching and learning using an interdisciplinary lens. Students in inclusive STEM-focused high schools, for example, apply a variety of STEM-related skills in contexts that help them understand the connections among school, community, work, and the more subject-specific knowledge they are gaining (Lynch, 2014). These learning experiences occur through multiple opportunities for project-based learning and student production that are facilitated during and beyond the school day. Technology is used to connect students with teachers, mentors, social networking resources for innovative STEM ideas, and STEM-focused data systems and research (Lynch, Behrend, Burton, & Means, 2013). Students also have opportunities through school-business partnerships that provide internships, mentorships, and collaborative projects (Lynch et al., 2013).

The PAST Foundation, as discussed earlier, also is supporting districts and schools, including those that are rurally located and have limited resources within the immediate community, in providing integrated STEM education through its blended TPBL model. The GlobalEd 2 (GE2) project is another innovative effort to harness the power of technology to expand student access to multidisciplinary STEM learning experiences. GE2 is a set of online, problem-based learning simulations for middle school students that uses social studies as an expanded, multidisciplinary curricular space for students to learn and apply scientific literacies and concepts in an international context. The development and evaluation of the efficacy of GE2 has been funded by IES.

The Verizon Innovative Learning Schools Initiative, one of two Digital Promise Schools Initiatives, is another effort focused on promoting innovative, cross-disciplinary learning environments using new educational technologies. The goal of the initiative is to close the digital learning gap among schools in the nation while promoting new approaches to interdisciplinary learning. The initiative focuses on providing access to mobile technology in the classroom and in the home, while at the same time establishing a community of practice that supports participants' effective use of the devices. Presently, the Verizon Innovative Learning Schools Initiative includes

21 partner schools and 10 partner districts from around the country. Pennsylvania's Elizabeth Forward School District, the superintendent of which served as a contributor to this project, is a partner in this initiative. Elizabeth Forward not only is using technology to re-think teaching and learning but also has leveraged the support of the initiative to develop a unified arts curriculum called the "Dream Factory." The Dream Factory is a collaborative workspace that brings together computer science, technology, and arts education, with the aim of allowing "students to better connect the subjects and understand how the concepts they learn overlap" (Coyne, 2014, para. 3). In the Dream Factory, middle school students work in teams, using the skills they are learning across the curriculum to access educational technology in project-based activities. The intent is for students to work together to create unique projects that they design and develop from start to finish.[30]

A 2014 report published by National Academies Press (NAP, 2014), *STEM Integration in K–12 Education,* also identifies and characterizes existing approaches to integrated STEM education in both formal and informal settings. The report also includes recommendations for designing, assessing, and researching effective integrated STEM experiences and can serve as a starting point for policymakers, researchers, educators, and professional organizations in their efforts to engage children and youth in more interdisciplinary STEM experiences (NAP, 2014).

One major challenge to achieving the widespread application of this element of the vision is supplying educators with the preparation, knowledge, resources, and strategies to effectively implement integrated and interdisciplinary STEM learning activities. Initiatives like the American Association for the Advancement of Science (AAAS) Project 2061 are one of many existing efforts to address this challenge. This initiative focuses on understanding, and ensuring that all students have access to, the resources and supports that need to be in place to help all students achieve STEM literacy. In collaboration with district leaders, practitioners, and scientists and experts on learning and curriculum design, Project 2061 aims to develop teachers' recognition of the interconnectedness of knowledge by providing supports that build their "knowledge of the nature and history of science, mathematics, and technology, an understanding of common themes that cut across the disciplines, and the development of scientific habits of mind as essential aspects of science literacy" (Kesidou & Koppal, 2004, p. 5).

The earlier referenced NAP report (2014) also provides recommendations with this challenge in mind. The report states that educators will need training and opportunities to work collaboratively with their colleagues, curriculum coordinators, and in some cases, in partnership with STEM professionals and researchers, to promote effective practice and delivery of integrated STEM lesson activities (NAP, 2014). Another key recommendation is for designers of integrated STEM experiences to ensure that they attend to the learning goals and progressions in the individual STEM subjects so as not to inadvertently undermine or stall learning in those disciplines (NAP, 2014). A final and critical recommendation is also for integrated STEM experiences to be researched and evaluated to build knowledge and understanding about the effectiveness of these experiences in promoting STEM learning and engagement within and across disciplines and the extent to which they are equitably accessed and meeting the needs of diverse learners (NAP, 2014).

Challenge 6: Re-envisioning the learning space. When members of the public think of the way in which students learn, they typically envision a teacher providing a lecture or students independently completing worksheet assignments, or occasionally solving a problem in a group- or project-based setting. This traditional method of teaching and learning does not take advantage of the new wave of technology innovation and flipped classroom approaches that provide a wider array of spaces and activities and can offer more inclusive and accessible STEM learning environments for all students.

One challenge, however, to promoting the more widespread and effective use of flipped classroom approaches and technology tools to provide flexible and inclusive learning spaces is the limited research, resources, knowledge, and expertise to which many educators have access. Thus far, most of the research on flipped learning approaches has relied on teacher and student self-reports (Hamden et al., 2013). In the area of education technology especially, the speed of product innovation (and procurement/adoption decisions) and conventional research and evaluation cycles are typically at odds. Research and evaluation studies proceed at a far slower speed than technology tool refinements and advancements are made. As a result, the adoption (or renewal) of educational innovations is often grounded in little or no evidence of effectiveness because the research is typically on tools that are no longer the most current.

There are efforts to promote more rapid-cycle research and development activities to build the evidence base for educational technology tools, such as OET's Rapid-Cycle Technology Evaluation project that aims to establish a standard for low-cost, quick turnaround evaluations of apps to understand how to improve outcomes of ESSA programs, as well as OET's Education Innovation Clusters, which work to encourage partnerships among researchers, entrepreneurs, and schools for developing new technologies. In addition, at the time of this report, the Department is releasing two new briefs highlighting the uses and benefits of rapid cycle evaluations (RCE). The briefs are based on the experiences of Race to the Top – District (RTT-D) grantees who participated in RCEs during the 2015–2016 school year to assess the effectiveness of specific personalized learning strategies they implemented under their grants. The RTT-D grantees are using the feedback to make decisions about scaling effective interventions to reach more of their students and schools. The first brief, *Improving Student Outcomes through Rapid Cycle Evaluation*, outlines challenges districts face at each stage of conducting RCE and how the challenges can be addressed. It lays out the three stages of RCE: formulate a question; design a study; and analyze the data to inform the decision. The second brief, A Primer on RCEs in the Race to the Top-District Program, is designed as a primer for districts considering whether and how they can use RCE and includes steps in determining how a district can get started.

The nation also can begin to draw on and learn lessons from innovative uses of learning spaces and technologies that offer students and educators the flexibility to move tools, collaborate around tools, and build or use physical, simulated, and virtual environments that adapt to the learning activity of the moment and apply UDL principles to promote accessibility and inclusion. Harvard's "black-box theater" classroom space can serve as one model for the future. This space is intentionally designed to be raw and unassuming, thereby inviting students to engage and interact with the technology, not feel overwhelmed or intimidated by it. As described by one contributor to this project who has used this space, students do not feel like the space is precious; they can mess things up, move things around, and be more playful. Everything—including the benches, whiteboards, monitors, and stools—is on wheels. Tables can be used independently or docked together for group work. Central to this space is that there is total mobility of equipment, and there is an abundance of flexible mechanisms for accessing electric power, including outlets on floors and ceilings.

National Geographic's BioBlitzes also are expanding notions of where learning occurs. BioBlitzes are learning events that provide an alternate education and learning model for STEM that engages the full ecosystem of partners in a student's education by using the natural world as the classroom. In these blitzes, a park or other natural area is selected for a 24-hour biodiversity count. Teams of students, families, and community members work alongside scientists to make observations, record data, understand classification, and map findings—a process that promotes citizen science and develops skills that scientists actually use in the field.

Efforts also are underway to start addressing specific issues in early learning. As discussed earlier, the Children's Museum of Pittsburgh serves as the site of two Head Start classrooms. Similarly, the Smithsonian Early Enrichment Center (SEEC) is an early childhood demonstration school for children ages 2 to 5 in which the museum's collections serve as the foundation for a culturally diverse curriculum. The children are placed at the center of every learning experience. They learn through personal encounters with scientists, such as paleontologists, when studying a unit on dinosaurs. As stated on the program's website, "Kindergarteners become 'scientists' in a visit to the Smithsonian Environmental Research Center where they explore nature intimately, make observations, test hypotheses, and discuss ideas with an entomologist" (Smithsonian, n.d., para. 4).

As another example, specific to the use of technology tools that can promote early learning, the Joan Ganz Cooney Center at Sesame Workshop recommends the Parent Choice Award Winners as a guide to help select child-appropriate apps to support learning (U.S. Department of Education, OET, 2016).

Massive open online courses (MOOCs) offer another burgeoning innovation that can transform the teaching and learning space for STEM. Although the success of MOOCs is thus far mixed, new experiences and knowledge is being gained and can be used to inform their evolution as technology matures and R&D to improve student engagement in online learning is advanced (Lewin, 2013). For example, instead of using one model for a STEM course, educators in STEM 2026 could use a continuum of online courses or MOOCs and connect them to in-person interactions to use best practices and students engage in online STEM learning.

MOOCs also may offer a strong environment for embedded intelligent tutoring systems like those described earlier (Educause Learning Initiative, 2013). Games and simulations, as well as adaptive learning technology like the intelligent tutoring systems already discussed, are already emerging as pedagogical tools and alternate, interactive learning spaces in some settings. In 2009–10, elementary and secondary students took approximately 1.8 million courses online, and close to 250,000 students in 2010–11 were enrolled in full-time virtual schools (Center for Public Education, 2012).

The technology advancements and tools that have supported these types of blended and online learning environments have the added benefit of supporting other key components of STEM 2026. These other complementary components of the vision that can be supported by technology-enabled tools include tinkering and the promotion of intentional play and risk taking, and customized activities that are designed to meet the learner within the context of his or her interests, learning preferences, and learning needs (U.S. Department of Education, OET, 2016). For example, digital settings and embedded personal response technologies such as simulations, collaboration environments, virtual worlds, games, and intelligent tutors allow for tinkering and failure in *safe and inclusive* environments that can promote frequent experiences of success as both novices and more advanced students move from one level to the next (U.S. Department of Education, OET, 2016).

Tools like EcoMOBILE and EcoMUVE, Foldit, and Minecraft, as mentioned earlier, also offer emerging examples of the opportunities that are becoming available for using technology-enabled tools to provide flexible and interactive learning spaces where students are the creators of their own STEM knowledge and potentially the field's. As reported in the 2016 National Education Technology Plan (U.S. Department of Education, OET, 2016), augmented reality technologies (like EcoMOBILE) can be used to support the learning of critical inquiry strategies and processes" (p. 16). Another existing example includes Zspace, a software program that provides students with 3-D glasses and a stylus to work "in the field" to investigate places and objects schools typically would not be able to access or afford, ranging from the layers of the earth to the human heart, to motors and batteries (U.S. Department of Education, OET, 2016). Similarly, an NSF-funded Extended Learning With Cyber-Enabled Tangibles project is investigating the In Touch With Molecules program that uses computer autofabrication to create tangible models of biological molecules and a linked computer software that allows high school and college students to interact with the tangible models using webcams and augmented reality (U.S. Department of Education, OET, 2016).

Many other technologies like these are becoming available, and emerging innovations are being developed and researched to refine existing tools and create new ones that apply UDL principles. Some researchers are exploring voice recognition and simulated human dialogue that is natural and improves the feedback cycle, particularly with respect to intelligent tutors, for example (Educause Learning Initiative, 2013). As this research continues and technology advances, there is the potential for augmented reality technologies, computer-aided instructional platforms, and intelligent systems to further allow teachers to customize their teaching and interaction (Educause Learning Initiative, 2013).

Challenge 7: Developing innovative and accessible measures of learning. Standardized assessments primarily measure student academic knowledge in core content and skill areas. When used well, these types of assessments provide necessary information for educators, families, the public, and students themselves to measure progress and promote equity. In excess or without clear purpose, assessments take valuable time away from teaching and learning, draining creative approaches from our classrooms (U.S. Department of Education, 2015). In addition, many creative students struggle in traditional classroom- and performance-based assessment settings; and the integration of more holistic measures of learning can provide accessible and inclusive mechanisms for gauging and deepening the diverse skills and knowledge students bring to the process of learning. In the context of STEM education, although many aspects of learning the STEM disciplines are cumulative, requiring certain foundational skills and understanding before a student can move on to higher levels of learning, content, and courses, not all cognitive progressions are linear (The XQ Project, 2016). Therefore, the STEM 2026 vision lends credence to the value of innovative and accessible measures of learning that deepen understanding of individualized processes of learning, including what approaches, materials, platforms, and settings work best in particular contexts to serve diverse learners.

Innovative and accessible measures of learning that provide personalized and in-time feedback to students in the moment of learning can provide students with opportunities to test out their skills with demanding content, and receive feedback on the creative ways they apply these skills to gain new knowledge. By emphasizing measures of learning that do not focus solely on mastery, we can better nurture growth mindsets among young children and youth as they build their identities and sense of belonging in STEM education (Boaler, 2016).

For this approach to take hold, however, educators need to be incentivized and not fear introducing students to STEM experiences that are harder to "test" and measure (e.g., participation in maker fairs, job shadowing, solving "grand challenges"). Educators also may be hesitant to introduce ideas and content that they think students may not be ready to master and thus may "fail" on a performance test.

Of course, a key challenge is that the research on effective measures of growth mindsets is limited, and there are validity concerns with existing indicators, including the possibility for situational and group-specific biases (Duckworth & Yeager, 2015). This challenge should not stall efforts to develop and implement innovative and accessible measures of learning. Rather, the enthusiasm for applying a more expansive view of student competence should bear in mind and "be tempered with appreciation for the many limitations of currently available measures" (Duckworth & Yeager, 2015, p. 237).

Steps are already being taken to reconsider and potentially reframe the future of education assessments, with guidance for doing so. President Obama presented an open letter to parents and teachers, outlining the movement to make test taking smarter (U.S. Department of Education, 2015). The Testing Action Plan outlines principles and steps that will "correct the balance" in test taking in our nation's schools. More importantly, President Obama indicates that testing should be one of many components used to assess student knowledge in content areas.

Another opportunity for developing innovative and accessible measures of learning that include UDL principles and validly and reliably measure and motivate diverse learners' growth in both content knowledge and lifelong learning skills is the growing recognition and use of real-time response systems and strategies. Measuring student learning as it is occurring allows educators the opportunity to assess and provide immediate feedback based on how they observe students taking in information and the strategies and skills they use to develop solutions. The policy, practice, and research challenges associated with spreading the accessibility and effective use of these types of real-time measures of learning, particularly those enabled by technology, are notable, particularly related to the development of new methods of data analytics in education, big-data processes, and ensuring compliance with data privacy requirements and accommodations for students with disabilities and ELs. Again, however, the nation can learn from emerging initiatives to inform the growth and propagation of personal response systems that are designed to offer more holistic approaches to understanding students' skills and knowledge, and addressing student needs in the moment of learning.

As discussed earlier, some programs and tools have been developed and are being used in school systems and classrooms across the nation already, including Carnegie Mellon's Cognitive Tutor Software and the previously discussed educational software programs that are specifically designed with accommodations for students with disabilities. Some schools also are integrating gaming into their instructional approach to engage students and as a means to more holistically measure students' learning and provide individualized, in-time support. For example, at the Quest to Learn Grades 6–12 school in New York, an inquiry-driven and game-based approach to teaching and learning is used. The approach integrates technology-embedded assessments to provide teachers with data on student learning in real time. As students engage in immersive and instructional projects focused on addressing real-world challenges, teachers use a rubric to observe and document students' demonstrations of skills and behaviors, thereby assessing students' learning and thinking in given moments of time and within a specific context (Flatt, 2014). This information is intended to empower teachers to provide immediate feedback, redirection, or support that guides students at critical points in the learning process (Flatt, 2014). Preliminary data analyses of the Quest to Learn model indicate that students are achieving significant gains in critical thinking, reasoning, problem-solving, and communication skills.

Challenge 8: Re-imaging the "face" of STEM to promote diversity and opportunity. Another key barrier that must be overcome to achieve STEM 2026 is the historical legacy of exclusion in STEM. As previously discussed, historical and sociocultural images of STEM that have shaped society's perception of who qualifies as a scientist, who is good at science, and who belongs in the elite of STEM CoP have been slow to change and do not reflect the full spectrum of our nation's demographics and pool of talent.

Pop culture and the media play a critical role in reversing stereotypes that affect STEM pathways and public understanding of the relevance of STEM to their everyday lives. High-quality educational tools and educational television programming, computer games, and apps can expand the ways in which young children are exposed to and gain experience in STEM. Programs such as *Sesame Street*, and more recently developed shows such as *The Magic School Bus*, *Sid the Science Kid,* and *Doc McStuffins* that portray racially and ethnically diverse girls and boys engaging with and applying STEM concepts in relevant ways, offer promising models on which the entertainment community can draw and innovate.

Television and the movies also are increasingly focused on STEM content, characters, and storylines. Shows like *Criminal Minds* and movies like *The Martian* have demonstrated the entertainment value of science (Coody Smits, 2016). They also underscore the value of not just weaving together a good story but one that is accurate. In 2008, the National Academies of Science (NAS) launched the Science and Entertainment Exchange, a program designed to connect entertainment professionals with scientists to ensure the development and production of engaging plot lines and characters based on accurate science and scientific work (Coody Smits, 2016). These types of collaborations, like the one described earlier between Disney, Google, and NASA, promote more authentic science-motivated narratives and images of scientists and how what they do can play a role in making STEM more relevant and appealing to more children.

These trends are encouraging, but media outlets must continue to be incentivized to proactively propagate new cultural signals and images that can change the face of STEM. While on the surface, many of the science-based shows and movies undermine long-held stereotypes, they also often end up reinforcing the status quo about women and people of color in STEM in their ultimate goal to entertain and engage the public audience (McIntosh, 2014). Moreover, persons with disabilities are notably absent in the popular media portrayals of scientists, innovators, and engineers (National Research Council, 2001).

The Geena Davis Institute on Gender in Media is making efforts to generate and share more research on reversing gender stereotypes in STEM. The institute encourages the creation of more diverse female characters in entertainment, especially media that targets children under age 12. The institute hosts a biennial symposium to bring together more than 300 individuals representing key decision makers, content creators, and thought leaders in media to share best practices and develop a framework for establishing a more gender-balanced landscape of the entertainment available to young children. The DO-IT Center at the University of Washington, the work of which has been previously discussed in this report, further aims to increase awareness of how people with disabilities can be successful in STEM through its Research in Disabilities (RDE) Collaborative Dissemination website. The site includes personal stories of individuals with disabilities about their achievements in STEM fields, as well as a photo collection of images from the DO-IT Center of students with visible and invisible disabilities using technology, participating in STEM activities, communicating with mentors, interacting with each other on science and engineering activities, and participating in field trips.

Other informal STEM education programs provide outreach and connections for working professionals of all backgrounds to directly interact with students, shaping their perceptions of what a scientist looks like. Large events like the USA Science and Engineering Festival (USASEF) serve as a catalyst, bringing scientists and engineers under one roof to meet over 350,000 students and members of the public in one weekend. Throughout the school year, USASEF brings more than 150 diverse scientists and technology professionals into K–12 classrooms throughout the

Washington, D.C., region, with a focus on underserved schools in communities of color. Many science festivals and STEM museums throughout the country have similar outreach programs that can be expanded to give students real interaction with a wide range of diverse working scientists.

As another example, NASA, held its first Google+ Hangout in February 2013 to introduce students to projects and stakeholders that have used social media to challenge society's perceptions of the STEM imagery. The #ILookLikeAnEngineer platform challenges common misperceptions about who engineers are by showcasing the vast diversity of talent in the technology industry. Hundreds of women and people of color use the platform to post images of themselves, describe the work they do, and why. Their pictures and stories offer illustrations of who succeeds and belongs in STEM that run counter to the predominant perceptions of engineers in popular culture. Similarly, Era of an Engineer, a firm founded by Young Guru, a Grammy-nominated engineer, DJ, and hip-hop record producer, highlights STEM professions in the music industry, such as audio engineering. The firm offers workshops and seminars for students to introduce them to these types of careers and the importance of learning and mastering coding and computer programs (DeMeritt, 2016).

[21] See http://home.cc.gatech.edu/ice-gt/594

[22] Data on the CalTeach program are available at: http://calteach.universityofcalifornia.edu/impact/index.html

[23] The crosswalk of the CSTA and CCSS standards is available at: https://csta.acm.org/Curriculum/sub/CurrFiles/CSTA_Standards_Mapped_to_CommonCoreStandardsNew.pdf.

[24] See http://futureready.org/about-the-effort/state-programs/ for information about these statewide Future Ready programs.

[25] See lesson plan at https://www.nps.gov/nr/twhp/wwwlps/lessons/21boott/21boott.htm

[26] See lesson plan at https://www.nps.gov/nr/twhp/wwwlps/lessons/111wrightoh/111WrightOH.htm

[27] The framework is available at http://www.ascd.org/publications/educational-leadership/dec14/vol72/num04/Tinkering-Is-Serious-Play.aspx#tinkering.

[28] This document can be accessed at http://innovation.ed.gov/what-we-do/innovation/ready-to-learn-television-rtl/

[29] These resources are available at http://www.bostonchildrensmuseum.org/sites/default/files/pdfs/STEMGuide.pdf.

[30] A brief video of the district's innovative approach to STEM education is available here: https://www.youtube.com/watch?v=TtGmMGqF-zE&feature=youtu.be.

Conclusion

For STEM education to have the desired effect of developing individuals' lifelong learning skills, as well as the potential for sustained interest in STEM topics and issues, children and youth should be exposed to positive and authentic STEM learning experiences as early as preschool and throughout their educational pathways (Moomaw & Davis, 2010). Introducing students to STEM early in their education, in both informal and formal learning settings, capitalizes on children's innate interest in the world around them. As Russell Shilling, the Department's executive director of STEM remarked, "Every child is imbued with a sense of curiosity and wonder. They are born scientists, engineers, and creators ready to discover the world at every turn. The goal of education should be to sustain engagement through a lifetime" (Shilling, 2015, para. 1).

STEM 2026 presents an aspirational vision for STEM teaching and learning that promotes such sustained engagement, imbuing all students and their surrounding communities with a belief that they can better their own lives and others through STEM. This vision, which developed out of a series of dynamic discussions among expert thought leaders and innovators in STEM education, comprises six interconnected core components:

- Engaged and networked communities of practice
- Accessible learning activities that invite intentional play and risk
- Educational experiences that include interdisciplinary approaches to solving "grand challenges"
- Flexible and inclusive learning spaces
- Innovative and accessible measures of learning
- Societal and cultural images and environments that promote diversity and opportunity in STEM

STEM education, comprising these six core principles, holds promise for powerfully transforming all students' access to and engagement in STEM. The coordinated involvement and pooling of resources among a range of stakeholders can, together, provide the research and evidence, the encouragement, the opportunity, and the access to high-quality STEM learning experiences to help ensure that all of the nation's children receive the education they need and deserve.

Certainly, challenges remain, but lessons can be learned and ideas for moving forward can be developed based on the work of present-day innovators, and regions, districts, schools, and community and nonprofit organizations that are already creating change. In this process of discovery and knowledge propagation, and through widespread CoP, the nation, as well as state, regional, and local networks of learning, can return to the STEM 2026 vision presented here to adjust and refine the future of STEM education as new experiences and new evidence are gained, particularly about what approaches work best in certain contexts and to serve diverse learners.

In conclusion, underlying STEM 2026 is a vision for an innovative future that allows for a backward mapping process. It is a process that stimulates action among key stakeholder groups and that helps identify what we know currently, what needs to be discovered, and what needs to be developed to achieve the ultimate goal—creating equity of opportunity in STEM to promote lifelong learning among the nation's youth.

Appendix A.

Project Activities for the Creation of STEM 2026

Developing a Bold Vision for STEM Teaching and Learning to Prepare Students for Lifelong Learning

Workshop 1: Developing the Foundation for the STEM 2026 Vision

The first workshop was held at the Department on March 15–16, 2015. This 1.5-day meeting served as the official launch of the discussion. Prior to the meeting, the 10 expert panel members were asked to write a thought piece in response to questions about what "success" in STEM means and what learning experiences and innovations will promote successful STEM pathways for all students:

- What will success look like in STEM education for students in 2026?
- How do we know what to train for if we don't know what the STEM jobs are in 2026?
- What kinds of learning activities will best enable students to be successful?
- What could STEM education learn from other disciplines and areas of study on innovation in teaching and learning (e.g., informal learning spaces, cognitive science, educational psychology, learning networks, neuroscience)? In what ways can these innovations transform teaching and learning in STEM?
- What promise does innovation in technology hold for education now and looking to the future? In what ways can these innovations transform teaching and learning in STEM?

The purpose of the prewriting exercise was to set the stage for the meeting discussions, activate the invited experts' imaginations, and introduce the diverse group of thought leaders to the experiences, perspectives, and innovations that already exist or are emerging in the field of STEM education. Selections from the thought pieces that were submitted by the invited experts are incorporated in this paper to illustrate key ideas that helped lay the foundation for the resulting vision.

The emerging vision that ensued from this first workshop served as the foundation for the remaining meetings among invited expert thought leaders and innovators.

A Vision for STEM Teaching and Learning to Prepare Students for Lifelong Learning

Workshop 2: Refining the STEM 2026 Vision

The second workshop also was held in Washington, D.C., at the Department. This 1.5-day meeting, convened on May 19–20, 2015, was designed to build upon the groundwork for the vision that resulted from the first workshop. Specifically, we asked this second group of eight experts to review the big ideas and emerging themes from the first workshop with the following goals:

- Refining the bold 10-year vision for STEM education in ways that truly disrupt and transcend current education policy, practice, structures, and physical and technological time and spaces.
- Specifying the innovative and disruptive learning experiences that will promote equitable access to and opportunity in successful STEM education pathways.
- Brainstorming the highest impact roles of the key stakeholders who are necessary for the propagation of successful STEM education pathways for all students in localized contexts.

Workshop 3: Finalizing the STEM 2026 Vision

The format of the third workshop differed from the first two and provided an opportunity to introduce and receive feedback on the vision with a key group of individuals who are traditionally not at the STEM education policy and practice table. Participants included STEM leaders in industry, entertainment, and academia. The Department and the AIR project team were invited to the third annual *Scientific American* and Macmillan Education Executive STEM Education Summit (STEM Education Summit 3.0) to present an overview of the STEM 2026 Vision and to facilitate an interactive discussion among the invited summit participants to solicit their reactions and ideas. This summit was held on August 4, 2015, at the New York Academy of Science. Participants were asked to respond to the vision with the following questions in mind:

- What "big idea" or key component is missing? This could be a stakeholder group that needs to be involved, a learning experience, a mode of instructional delivery, or an assessment mechanism that would "move the needle" in terms of thinking outside the box and outside of the status quo in ways that activate conversation and change.
- What actions or strategies would help propagate and push forward the bold vision for STEM education among your own networks and in collaboration with other networks?
- How can we ensure equity to engage all learners in this bold vision?
- What actions or strategies would enable the U.S. Department of Education to have the highest impact role in terms of creating policies and incentives that will propagate locally grounded STEM education learning networks in all communities?

In responding to these questions and the vision, participants were encouraged to draw on their unique perspectives and experiences as well as to think "outside the box," without the constraints of current systems, structures, policies, or sociocultural barriers. To further prompt their thinking, the *Scientific American* audience was asked to consider, for example, notions of "propagating" versus "scaling" the vision (i.e., strategies for promoting the vision that allow for flexibility, cultural relevance, and adaptation within local contexts and communities versus a one-size-fits-all model), alternative research models for promoting innovative teaching and learning experiences, interdisciplinary approaches that reduce stovepipes among STEM and non-STEM subjects, real-time formative assessment and active learning, and highly personalized learning.

Workshop 4: Articulating the Potential of the STEM 2026 Vision in Practice

For the fourth and final panel, the project team asked select participants from previous panels as well as thought leaders in the field who we had not yet engaged in the discussion to develop short vignettes to illustrate the potential of the STEM 2026 Vision. Specifically, they were invited to respond to the following:

> Imagine it is the year 2026. In a correspondence to a friend, describe a specific community, school, learning experience, or classroom that exemplifies your greatest "vision" or "dream" of an ideal STEM teaching and lifelong learning world. When you walk into the learning environment, what do you see? What's the student and teacher experience? What big changes have occurred?

Appendix B.

Vignettes Illustrating the 2026 Vision for STEM

Introduction to the Vignettes

The following vignettes were authored by experts and thought leaders in STEM teaching and learning. The purpose of the vignettes is to illustrate the potential of the STEM 2026 Vision to transform engagement and participation in these critical fields, from early childhood through higher education and beyond. The vignettes describe new approaches to teaching and learning as well as innovative tools that can transform the STEM education enterprise. They highlight the perspectives of educators, learning facilitators, and students in the context of formal and informal learning settings. Whereas some of the vignette authors asked to be identified, others chose to remain anonymous. A list of the individuals who contributed to the vision described in the main report, including those who served as workshop participants or vignette authors, is provided in the Acknowledgments.

Infusion of Advanced Manufacturing Techniques and Tools Into the Classroom

Aprille Joy Ericsson *Innovative Technology Partnerships Office, NASA Goddard Space Flight Center*

As I look forward to the future, there are a few technical areas that I deem imperative for the world's success in producing cutting-edge and innovative technology. Advanced manufacturing is just such a technical area.

"Advanced manufacturing centers upon improving the performance of U.S. industry through the innovative application of technologies, processes and methods to product design and production."[31] A recent survey of advanced manufacturing definitions by the White House states: "A concise definition of advanced manufacturing offered by some is manufacturing that entails rapid transfer of science and technology (S&T) into manufacturing products and processes."[32]

With that mindset, the success of advanced manufacturing is indicative of "the rate of *technology adoption* and the ability to use that technology to remain competitive and add value define the advanced manufacturing sector."[33] Fortunately, the world of advanced manufacturing has remained dynamic and is moving forward by leaps and bounds. It has transitioned from traditional manufacturing, to manual assembly-line production, to robotic/mechanized production, which largely uses detractive manufacturing processes. Fortunately, advanced manufacturing is most well known for the world's new love interest, 3-D printing.

Industry and government have moved forward to embrace and incorporate 3-D printing/additive manufacturing processes and standards into research institutions and mainstream industry. Its applications span all engineering disciplines. Also, it has afforded a more rapid robotic production of intricate single-piece components made with “green” materials that no longer leave 50 percent to 80 percent of the material on the cutting room floor, thus fully embodying the concept of sustainability. In addition, additive manufacturing has started to provide tolerances specifications to microscale and nanoscale feature sizes.

The exciting aspects of 3-D printing are the cross-disciplinary applications from traditional manufacturing arenas like the automotive and construction industry to nontraditional arenas like medicine, art, clothing, and food industries. Many of us can remember the *Jetsons and Star Trek*, where just about anything, including food, could be ordered from a console. The cool thing is that this process has been replicated in a space environment on the International Space Station when NASA beamed up (e-mailed) a computer-aided-design (CAD) model for a socket wrench, and it was manufactured with a microgravity 3-D printer on board. Recently, NASA contracted a small business to study the feasibility of 3-D printing food in space. Check out the YouTube video of a 3-D printed pizza (https://www.youtube.com/watch?v=ISXqC-YPnpc) (baked pizza product: https://app.box.com/s/a1tltitlvmvulkjfkw9m).

Not only has the 3-D printing process become available for rapid prototyping of an aerospace engineer’s design in a NASA laboratory, but also now it is feasible for libraries, schools, and homes to afford a 3-D printing machine. Revolutionary classroom laboratories can incorporate a “Fab Lab” concept (an outreach project born at the Massachusetts Institute of Technology’s Center for Bits and Atoms) into their space fairly efficiently, with the central tool being a 3-D printing machine. Currently, Fab Labs have spread from inner-city Boston to rural India, from South Africa to north of Norway.

Educational access to 3-D printing capabilities should not be an anomaly but a vital component in educational institutions. This manufacturing tool will take the concept of shop class to a whole new level, ultimately rebirthing the idea of innovation through tinkering in an ecological, cost-effective, and timely manner. Students can create inexpensive models for inspection and touching, like 3-D printed replicated dinosaur artifacts and cross-sections of human organs. They also can create a new rocket engine or prosthetic limb without the fear of costly reduplication efforts after an initial failure.

For optimal utilization of this technology, it would be best for teachers and students to learn and demonstrate programming skills like CAD. However, this additive manufacturing tool still can be effectively used through open-source designs and recipes for a multitude of products.

“*Forbes* investment pundits have predicted that 3-D printing may lead to a resurgence of American manufacturing, citing the small, creative companies that comprise the current industry landscape and the lack of the necessary complex infrastructure in typical outsource markets.”[34] Who knows, but I foresee a new volume of cross-disciplinary technologists exploding forth, equipped with computer programming skills and armed with a 3-D printer.

Vignette on Learning: A College Freshman's Perspective in 2026

Robert Lue *Harvard University*

I feel like I am in the driver's seat, and that's a good feeling to have—especially in my first year in college. I was nervous coming to such a large state school when my high school class was less than 40 students, with most of us coming from the surrounding rural areas. But, this first year has been amazing; I feel stimulated, excited to explore, and best of all, well prepared for this next step in my education. In high school, we emphasized mastering fundamental concepts and skills using a combination of online tutorials and simulations that were then connected with group work, pushing us to apply things further when we met in class. The online materials allowed me to learn the basic language and approaches of science, and practice applying my knowledge of mathematics to calculations in biology, chemistry, and physics. Receiving immediate feedback from the online tutorials let me know how I was doing in real time, and I could keep pushing on my own until I had the basics comfortably covered. So when I came to class, I could work in a group and feel confident that I was on solid footing with my peers. My teachers also knew how my learning was progressing outside of class using the analytics they received from the platform. Thus, when I was struggling, I could always count on them reaching out to help with those additional resources (online and in person) to get me through a rough patch. It also was great that these foundation-building resources were selected for us by our teachers in partnership with colleges and universities that would hopefully be in our future. It was very comforting knowing that our high school teachers were connected with college teachers and together curated a foundation that would serve us well going forward.

And serve me well, it did! I was fascinated by biology in high school and got a sense of how useful chemistry and physics could be when applied to biology, but college has transformed my view of how interdisciplinary real science actually is. My freshman science courses don't fit comfortably in just one "field"; instead, they focus on issues of wide concern and allow me to apply the methods and ideas from different fields to address them. My life sciences course lets me use my knowledge of chemical kinetics and thermodynamics to tackle how small molecule drug binding can be optimized for a therapeutic target. Of course, I need to dive deep into the cell and molecular biology to understand the disease and mechanistic basis for therapy; bringing all of this together through a series of provocative and design-oriented classroom sessions has been exhilarating. Like in high school, I continue to use online resources to fill my tool belt, but now I play a bigger role selecting what I need from a repository that the school provides for me. Classroom sessions are more interactive than ever, and my professor spends most of her time working with us in groups and individually to realize our proposals. The labs are a combination of basic methodology and skill building coupled with our own experiments designed to prototype ideas. Our teamwork is designed to leverage different opinions and approaches, and our teacher has helped us understand how to use not only the resources in the research literature but also each other as critics, collaborators, and partners in learning. This alone has changed me profoundly this freshman year. My class is so diverse, so much more so than my high school, and my courses have taught me to cherish this diversity—from classmates' wildly different backgrounds and perspectives to how these are brought to the foreground by the equally varied methods of individual and group work that we do in the classroom. In fact, the classroom no longer feels like a classroom for taking courses; it feels like some kind of laboratory or incubator where I get to explore, collaborate, and discover at the same time I learn about science. I love it, and can see why science must be a part of my life going forward!

Untitled

Anonymous Contribution

I just came back from a school visit that I'm dying to tell you about. I'm not sure where to start. First of all, there were so few traditional classrooms or lectures. In the course of the day, I saw students in small groups with a teacher, working on mastering a skill or debating a concept or doing a lab. I saw students working alone, reading, researching, and writing, as a teacher circulated, asking this awesome question: "What are you struggling with right now? How can I help you get to the next level?" and then actually prompting the student to the next level—or assigning herself the task of figuring out what help the student needed. Then (inspired, I wonder, by all the research back around 2014 about adult learning), much of the day was spent applying the learning in real-world situations, with kids building things, taking them apart, designing experiments, and collecting results.

Which, by the way, was made easier by the fact that (forgive me for burying the lead) this school was integrated into the new Stryker campus (you know, that company that makes medical devices). I'm not talking "stand-alone building tucked away on the corner of the lot" integrated. I'm talking classrooms next to—and sometimes inside of—labs and conference rooms. A few years back, Stryker made a commitment for 10 percent of its workforce to contribute 20 hours a year to STEM mentoring, but making real on that commitment was almost impossible inside its bottom-line corporate structure; it was just too hard to get the staff out in meaningful ways into schools. So instead of giving up on the commitment, Stryker went the other way: It brought the students and teachers to it. The results were electric: The learning was deep and relevant, teachers seemed to be having a ball, and, according to the human resources liaison at Stryker I chatted with, employee retention has gone through the roof. They just love having the kids and teachers around and being reminded of why they studied engineering and biochemistry in the first place.

It's interesting; there are three types of knowledge kids need: facility with core knowledge, ability to access knowledge that they don't know by heart, and capacity to generate new knowledge. I saw all three of those happening during the day. And it happened in a way that gave students' autonomy over their learning, allowed them to feel mastery, and incited their curiosity and drive to explore and discover. I saw a student meeting with her advisor to change her schedule to give her more flexible time to work on a research project she had taken on in one of the labs. I saw another student asking for extra support—can you imagine?! Everything was scaffolded and leveled so students were motivated to take the prerequisites to allow them to do the cool stuff they saw their older peers doing. So, for instance, you couldn't be part of the highly sought after engineering elective if you hadn't done algebra and geometry. Students sat down with a counselor and student mentor (in a pair) at the start of high school and each semester to talk about their goals to ensure they were doing the things they needed to do to get there. (Which, by the way, also involved contributing back to their communities—it reminded me of the way the NY Road Runners started making volunteering a requirement for entry to the marathon, in addition to running the requisite number of races. Giving back to the community is embedded in moving ahead.) In a nod to Montessori, there aren't grade levels per se, just mastery. Every kid has a version of an individualized education program, and the school does its best to position everyone as a learner moving along a learning trajectory, with different skills and challenges. Because so many kids come in behind, there's a lot of emphasis in the first year on shoring up core skills and knowledge, and kids who ask for extra support are held up as models for the community. All that stigma—for both high performers and low performers—seems to be totally absent.

I could go on and on, but if I had to boil it down, here's what I saw: (1) The notion of who is a teacher was exploded open, with STEM professionals, counselors, advisors, and master teachers all playing a critical role in educating the students; (2) kids were masters of their own learning, setting their agendas, pulling in help, slowing things down or speeding things up as they needed, and the system was responsive to their needs; (3) learning and application were wholly integrated, so everything was relevant; (4) this was no light-touch "themed" school: science, mathematics, and engineering were at the core of the school, and everything revolved around those subjects. Students were writing expository essays, reading Shakespeare, and learning American history, but S-E-M were constantly present; and (5) there was a real sense of purpose and meaning for everyone involved.

It was breathtaking. It made me want to quit my job and sign up to teach!

Untitled

Christian Schunn *University of Pittsburgh*

I was there for most of the 120-minute period. Physically, the space was recognizable as a classroom structured for group work, with some modern twists beyond what we experienced back in the day and also much larger to support 48 kids and two teachers. There were long tables with two laptops at one end and a large group-work space at the other end of each table. There also were six wall projectors around the room that could be controlled by one of the laptops or a student smartphone. It was interesting to see that these projectors had teacher-controlled default content, so that when students weren't actively controlling one of these, the four displays alternated every five minutes with phase-relevant project guidelines and interesting resources the teachers must have recently found of relevance to the projects.

I have never seen such a range of ages inside one classroom, both physically and virtually! I didn't quiz them, but some of the youngest kids looked like they were in sixth grade and some of the oldest kids looked like they were in 11th or 12th grade. Each group of about seven or eight kids had their own interest theme, and there clearly was a lot of mentoring going on, although sometimes of younger kids mentoring older kids on the use of a program. I was reminded a lot of what I had seen in First Lego League (FLL) competitions, with each team doing a lot of mentoring of new members into the different skill sets needed. And also similar to FLL was the use of adult mentors, but here in virtual form and beyond the two teachers were roving around the room as more general guides. Mostly the teams interacted by e-mail with the mentors, but, in one case, they had a videoconference going as the team was brainstorming about causes of a new problem that emerged when they surveyed the community about their prototype plan. It looked like these outside mentors were alumni from this school, now working out in the community in an area closely related to the team's project. The teams also were doing a good job of divide and conquer, so no one was sitting around just watching or goofing off. These large community-based projects have so many meaty aspects that it was clear that everyone had a major task to do.

Schools and MakerSpaces in 2026—Focus More on Design Thinking, Computational Thinking, and Digital Fabrication

Todd Keruskin *Elizabeth Forward School District*

In the 20th century, slide rulers, calculators, pencils, pencil boxes, and textbooks were school supplies students used on a daily basis. In the year 2026, all schools across the country will be transformed from the *Flintstones* days to more like the *Jetsons* or from Frontierland to Tomorrowland. All students will have their surface devices already programmed with their e-textbooks; apps that will personalize the learning for each student; 2-D and 3-D design software; computer programming software; charging stations in classrooms, hallways, and cafeterias; and portable 3-D printers. Classrooms in 2026 will look completely different from the institutional white walls and desks in a row in the 20th century. In 2026, classrooms will be more like Google office spaces, with fun colors, creative themes, collaborative spaces to promote project-based learning, and interactive devices to take learning to a deeper level for all students. In the year 2026, Grades K–12 students will focus and learn computational and design thinking skills, and they will have the ability to learn from different teachers according to their need, which is learning without the silos of teaching. For example, students will have the ability to work with an art teacher, a computer science teacher, or technology education teachers to design and make anything they can dream. Every student in the year 2026 will have their own 3-D printer and have access to digital fabrication equipment in elementary, middle, and high schools. Students in 2026 after graduation will have Grades K–12 integrated computational thinking skills to help them become computer and software engineers, design thinking skills and digital fabrication skills to help them become industrial or mechanical engineers, and design and art skills to help them become 2-D or 3-D digital artists.

Untitled

Howard Gobstein *Association of Public and Land-grant Universities*

Shir is beginning her college education at a public university. Her academic advisor guided her in selecting a statistically oriented series of mathematics courses to give her the skills she needs in her intended major of international business/relations. She realized she did not need the traditional algebra/calculus course sequence and was pleased that her university had worked with other universities and community colleges throughout the state to develop expanded and rigorous mathematics options, which are fully transferable across two- and four-year institutions.

Her statistics class is stimulating and challenging. There are periodic short lectures to introduce material for which there are follow-up online exercises. The professor and a team of instructors and graduate students monitor analytics embedded in the software in the online work of each student to enable them to track progress and identify which students are having difficulties with which concepts. Based on this analysis, the software, augmented by the team of instructors, can provide "personalized instruction"—targeted exercises for those students having particular difficulty in grasping a particular concept. During much of her class period, Shir is fully engaged with a small group of students huddled around a large computer screen discussing a problem keyed to recently introduced material and her own progress in understanding it. This week, Shir and her group are analysts for a major international corporation—how would they advise their chief executive officer on the benefits of a proposed international trade agreement among a key block of trading countries? They are energetically discussing potential approaches to analysis and presentation of trade data for particular products as well as how to estimate future trade based on alternative scenarios. Specially trained upper-class “learning assistants” are roving around the class to provide hints to students and answer questions on potential analytical tools. This real-world case study enables the students to learn concepts together, like statistics precepts, as they also pick up presentation skills and learn how to work in groups.

Untitled

Anonymous Contribution

The year is 2026, and the President of the United States has launched a nationwide initiative called STEM for a Transformative Future. The work is focused on high-need, but highly aspirational, immigrant communities where a modest investment in STEM learning opportunities for young people pays off with a 20-fold increase in young people going into STEM majors and careers.

The project is modeled on the successful Queens 2020 initiative, launched by the New York Hall of Science and a broad range of community partners in 2016, with the goal of establishing Queens as an enterprise zone for STEM learning. Queens, often referred to as the crossroads of the world—with a population of 2.3 million people, nearly half of whom are immigrants—has long served as a fertile ground for aspiring families. Immigrant families come from all corners of the globe with a singular goal in mind: to seek greater educational opportunities for their children that will lead to economic advancement. Mathematics and science are recognized as key drivers of future success.

Leveraging interest *and* aspiration, STEM for a Transformative Future creates dense networks of STEM learning opportunities in a wide range of community settings. Makerspaces that support innovation with cutting-edge tools and technology are springing up in church basements and barbershops; early learning centers are engaged in creative STEM projects such as making Play-Doh robots, creative circuitry, lantern making, and spooktacular monster making, which support educators, children, and families in tinkering, designing, and creating together. Middle school students have access to the latest and most exciting technologies in afterschool programs that take as their starting point students’ passions and interests. High school students are learning computer science through applied problem solving that places them in internship positions with community agencies that are looking for technology-based solutions to sustainability challenges such as smart water use, carbon monoxide reduction, composting, and waste disposal and treatment. Foundational to this work is a philosophy of deeper learning and deeper engagement, which supports students’ active engagement in STEM learning through the following principles:

- Play and people at the center of the learning activities
- Divergent solutions (where there is not only one right answer but multiple pathways and outputs through which learning takes place)
- Students as creators and publishers (where they create learning exemplars for sharing and reflecting on with others)
- Sharing and collaboration (where teamwork and the exchange of ideas is essential to complete a task)
- Engaged learning in contrast to rote memorization (intrinsic learning rather than skill building through extrinsic rewards)

Vignette Based on EcoMUVE and EcoMOBILE

http://ecolearn.gse.harvard.edu

Chris Dede *Harvard Graduate School of Education*

"We can use this tablet connected to a probe to figure out how much dissolved oxygen there is in a real pond during the field trip tomorrow," Dominique said to her teammate Andre in their middle school classroom. Dominique had the role of the water quality specialist in the virtual pond ecosystem and collected measurements of turbidity, dissolved oxygen, nutrients, pH, and temperature in her effort to determine the cause of the fish kill in the virtual world. Andre, in the role of the naturalist, had used a camera tool and virtual field guide to learn about the organisms in the pond and had reminded her that fish need oxygen to survive. They had added a link between fish and oxygen to their team concept map. Dominique had noticed that the dissolved oxygen measurements in the virtual pond changed over time, and now she could use her handheld probes to measure a "normal" amount of dissolved oxygen in a healthy pond.

Mr. Chen reviewed the online concept maps the students had created and looked for similarities across the groups. He noticed that some students hadn't included the storm sewer pipe or the runoff it might carry to the virtual pond. Mr. Chen used EcoMOBILE's Augmented Reality (AR) interface to geo-reference Everett Pond and highlight the location of a storm runoff drain. As a result, during the field trip, students would be able to see on their tablet display a flag denoting the location of a point of interest and also access additional information about the runoff pipe.

At the pond, Andre told his teammate Michael, "I'm using the tablet camera to take pictures of real organisms." "Hey! There's a flag over there!" Michael replied. The scene on their tablet overlaid a red flag in the bushes near the shore of the pond. Michael and Andre walked over to find a water runoff pipe leading into Everett Pond. "Whoa!" Andre exclaimed. "It looks just like the one between the housing development and the pond in the virtual world. Michael snapped a photo of Andre standing in front of the pipe, then read the information Mr. Chen had provided.

Michael, in his role of investigator, made a recording of Andre as he described what they thought the pipe might mean. They rushed back to the other side of the pond to show their teammates, Dominique and Sophie, their photos. "We just finished taking turbidity, dissolved oxygen, temperature, pH, and nutrient measurements with all the different probes," said Sophie, the microscopic specialist. "Let's see if the measurements near the pipe are any different."

This time the AR showed a virtual park ranger standing next to the pipe. The students interviewed this agent and learned about a problem that had arisen at Everett Pond last year. "This sounds like what is happening in the virtual pond," said Sophie. The ranger showed a simulated image of Everett Pond if the problem failed to be addressed.

When they returned to the computer lab the next day, the students created digital artifacts using the photos, voice recordings and data they had collected, and uploaded them to a Google Earth map of Everett Pond. Mr. Chen led a discussion about how their digital artifacts related to observations they had made in the virtual world. The students returned to the virtual world to reexamine their evidence about what was causing the fish in that pond to die.

[31] https://en.wikipedia.org/wiki/Advanced_manufacturing
[32] https://www.whitehouse.gov/sites/default/files/microsites/ostp/advanced-manuf-papers.pdf
[33] https://en.wikipedia.org/wiki/Advanced_manufacturing
[34] https://en.wikipedia.org/wiki/3D_printing

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