Next Generation STEM Learning for All

ENVISIONING ADVANCES BASED ON NSF SUPPORTED RESEARCH

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SRI Education

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Executive Summary

How can research-based findings and advances help society to re-envision STEM learning and education?

Prominent scientists in science, technology, engineering, and mathematics (STEM) learning research came together with school, community, and policy leaders at the National Science Foundation (NSF)-supported STEM Forum, held on November 9, 2015, in Washington, DC, to address this and other questions related to STEM learning. Attendees discussed both a specific opportunity, framed by President Obama's call for Next Generation STEM High Schools (The White House, 2015), and strategies to improve STEM learning in all types of schools and communities, whether or not the communities are part of the Next Generation STEM High Schools movement. What made the Forum unique was the comprehensiveness and quality of the research as well as the breadth of stakeholders from education, policy, innovation, and research contexts who participated in intensive discussions to connect this research to next generation STEM learning models.

The STEM Forum exemplified how diverse stakeholders can work together to envision, create, and implement successful STEM schools and STEM learning experiences. Building on the diversity of the participants, issues of social justice and equity rose to the fore, and strategies for addressing equity were featured. Challenges of scale and sustainability were also raised, and participants articulated the promise of new and emerging strategies. Important takeaways emerged across four thematic areas—research-based advances, multiple stakeholder communities, social justice and equity, and scale and sustainability, each of which are discussed below.

Research-Based Advances for STEM Learning

A strong body of research-based knowledge is available and ready for incorporation into the design of successful STEM programs and Next Generation STEM Schools. For example, participants shared mature research on concepts such as project-based learning, authentic learning experiences, learner-centered tools for engaging in modeling activities, and technology-enhanced representations. Forum participants noted the need for new assessments of student learning that could more faithfully measure the intended knowledge and skill outcomes—such as computational thinking at a middle school level or capturing communicative, creative, or practical use of STEM knowledge. Participants also noted that implementing effective and engaging teacher professional development remains a pervasive challenge, requiring advances in how to better prepare and support teachers to engage in innovative STEM approaches.

Multiple Stakeholder Communities around STEM Schools

Both research-based programs and operational STEM schools have found that partnerships are essential to successful STEM programs. Partners external to schools and STEM programs in other educational settings provide students and teachers with critically important STEM learning experiences, knowledge, and mentoring. Attendees shared how they were actively engaged in building partnerships among K–12 schools, higher education, industry, community-based organizations, policymakers, federal agencies, practitioners, and the public and why these and other stakeholders are crucial to conceptualizing, creating, and sustaining Next Generation STEM Learning for All. Further, attendees at the Forum advocated for conceiving of new STEM schools as smart and connected; that is, STEM learning environments should not be limited to within school walls, but should be integrated in communities and should leverage technology to connect people and resources, both place-based and remote.

Social Justice, Equity, and Excellence in STEM Schools and Communities

Across multiple working sessions, attendees characterized STEM learning as a social justice issue. Assuring access to STEM learning for learners traditionally underrepresented in STEM fields can provide opportunities for individual success as well as broader changes that contribute to social justice. Additionally, using a social justice lens to actively engage learners in STEM content provides motivation and engagement not found in decontextualized academic knowledge. Work is under way in inclusive STEM schools to look carefully at how their designs and strategies can encourage broadened participation and to study alternative ways of thinking about motivation, engagement, and persistence. The Forum provided opportunities for researchers and practitioners to describe how social justice in practice varies for different groups, including girls, students with disabilities, and other students traditionally underrepresented in STEM. Even so, more effort is needed to define targeted strategies to align STEM learning innovations with the local context and students' realities.

Scale and Sustainability

Although many long-standing and large-scale programs and models were presented, all attendees agreed that scaling and sustaining STEM learning innovations is challenging. Key approaches used by projects include (1) addressing scale and sustainability early in the program design and improvement process, (2) leveraging existing institutions or common resources by integrating novel resources or programs into ongoing program models, and (3) maintaining a strong focus on long-term partnership development. Participants are actively seeking new approaches that align multiple stakeholder groups around common issues and goals while leveraging unique stakeholder interests and capacities to forge common solutions.

Background

Schools that focus on STEM have emerged across the United States in response to the need for new and better ways to encourage STEM learning and thus address the shortage of STEM professionals in this country. Such STEM-focused high schools, especially those that are inclusive of students from groups who are historically underrepresented in STEM, are gaining recognition as potential vehicles for enhancing the equality of educational opportunity. There has been a good deal of support from prominent sources in recent years for expanding STEM-focused high schools, particularly inclusive (rather than selective) STEM high schools, as reflected in, for example, 2010's Prepare and Inspire: K–12 Education in STEM for America's Future (Holdren, Lander, & Varmus, 2010) from the President's Council of Advisors on Science and Technology (PCAST).

In 2008, Representative Frank Wolf (Virginia) requested that the NSF identify highly successful STEM-focused K–12 schools and programs. At the time, limited research existed on STEM school and/or program effectiveness, and no common definition of STEM schools and programs existed. NSF, in collaboration with the National Research Council (NRC), convened expert committees to outline criteria for identifying effective STEM schools and programs. NSF has since funded a series of research efforts to clarify the nature of STEM schools and their outcomes, stimulated in part by recommendations from the 2011 NRC report Successful K–12 STEM Education: Identifying Effective Approaches in Science, Technology, Engineering, and Mathematics and the proposed STEM indicator system for tracking progress toward the recommendations presented in a 2013 NRC report, Monitoring Progress Toward Successful K–12 STEM Education: A Nation Advancing?

President Obama's 2015 State of the Union address called for Next Generation High Schools, with an emphasis on innovative school models that would increase STEM opportunities for historically underrepresented students. In March 2015, President Obama announced $240 million in new private-sector commitments to inspire and prepare underrepresented students to excel in STEM careers through investments in high-quality STEM-focused schools and programs. With regard to both inclusive STEM schools and broader access to high-quality STEM teaching across all schools, he backed the Educate to Innovate campaign and the 100Kin10 networked effort to recruit 100,000 new STEM teachers and to open 1,000 new STEM-focused schools over 10 years. President Obama further underscored his support of inclusive STEM high schools by including $125 million in his 2016 proposed budget for Next Generation High Schools to create and sustain STEM-focused schools that improve readiness for postsecondary education and careers in STEM fields, especially for historically underrepresented groups in those fields.

Researchers and legislators echoed the president's emphasis on creating access to high-quality STEM teaching. In June 2015, the Institute of Education Sciences (IES) identified a new priority research area for its Investing in Innovation competition, calling for proposals that identify strategies to improve postsecondary STEM readiness in Title I schools. In July 2015, the U.S. Senate proposed an amendment to the reauthorization of the 1965 Elementary and Secondary Education Act (now Every Student Succeeds Act), prioritizing the creation and enhancement of STEM schools and calling on IES and NSF to coordinate evaluation of these schools' impact and to collaborate on a strategy to identify and disseminate best practices in high school STEM education. Inclusive STEM-focused high schools have emerged as a strong model with potential for enhancing equality of educational opportunity, and thus, as a Federal policy priority.

Forum Overview

These initiatives and developments in support of Next Generation STEM learning set the context for the one-day Forum on "Next Generation STEM Learning for All," held November 9, 2015. The Forum was organized by Education Development Center (EDC) and SRI International through the STEM Learning and Research Center (STELAR), the Center for Innovative Research in Cyberlearning (CIRCL), and the Community for Advancing Discovery Research in Education (CADRE), working in close collaboration with NSF and the White House Office of Science and Technology Policy.

The Forum served as a prelude to the first-ever White House Next Generation STEM High School Summit, held the next day, which focused on next-generation learning through the cultivation, growth, and long-term sustainability of redesigned high schools and local learning ecosystems, with the ultimate goal of advancing students' postsecondary education and career readiness in STEM. The Forum engaged participants, including policy makers, business leaders, philanthropists, education advocates, district and school leaders, teachers, and students, and a broader group of NSF-funded researchers and developers in contemplating how NSF's investments in research and development can best support national and local initiatives around the design, improvement, scale-up, and study of STEM-focused programs and high schools nationwide. The Forum launched with a plenary session that provided a glimpse into today's successful inclusive STEM-focused high schools, allowing participants to envision the next generation of STEM learning and schools. Twelve concurrent sessions following the plenary addressed critical areas and key features of high-quality STEM teaching in multiple contexts identified by emerging research findings, from reform priority areas identified by the White House, and from other relevant NSF program priorities. Across all sessions, four key themes emerged:

- Several key research-based advances highlighted at the Forum can significantly and positively impact the design and implementation of STEM learning experiences.
- The field must work to substantively engage multiple stakeholder communities who are vital to the success of STEM schools.
- All stakeholders must share a commitment to equitable access to high-quality STEM learning experiences for all learners and for their communities.
- More work is needed to define and design strategies for achieving scale for STEM schools and STEM learning experiences and ensuring their long-term sustainability.

Goals for the Forum

The Forum was designed to bring together relevant stakeholders and change agents to discuss recent NSF-funded research studies on STEM learning, to synthesize key findings across studies, and to provide rich opportunities for expanding cross-sector partnerships among participants. The Forum had three main goals:

1. Showcase NSF-funded research and development, and inform policymakers about the potential to transform STEM learning and education
2. Engage a broad community of stakeholders in envisioning the future of STEM learning and in strategizing how to best achieve collective impact
3. Facilitate networking across stakeholder groups to leverage skills and strengthen connections, collaboration, and coordination toward national goals for STEM education

Participation, Reach, and Dissemination

The one-day Forum featured 80 speakers who represented work funded by a wide range of NSF programs and directorates, and who participated in 12 concurrent breakout sessions, plenary remarks, and a poster session. In total, 250 people attended the event.

The lessons learned at the Forum spread far beyond its participants, due in part to a strong social media presence. By the end of the day, the hashtag #NSFnextgenSTEM resulted in 589 posts, 160 views, 3,802,468 impressions, and close to 1 million unique users who saw at least one tweet from the event. Information about the event has been disseminated through a variety of sources. A Storify of tweets from the day was created to showcase highlights from the event and reach a larger audience. The website for the Forum serves as a repository for all session materials and recordings, and has been promoted widely by NSF resource centers and networks, including CADRE, CIRCL, and STELAR. The Forum's reach continues to grow; it was featured at the February 1, 2016, STEM Smart Meeting, and will be featured at the NSF Innovative Technology Experiences for Teachers and Students (ITEST) Summit in May 2016 and the NSF Cyberlearning 2016 Meeting in June. The theme of the upcoming NSF 2016 Video Showcase, "Advancing STEM Learning for All: Sharing Cutting-Edge Work and Community Discourse," builds on the Forum's theme. All of these events strive to broaden participation in and access to high-quality STEM experiences, which will increase momentum around Next Generation STEM Learning for All.

Fostering and Implementing Research-Based Advances, Including Multiple Stakeholders, Promoting Equity and Social Justice, and Moving to Scale

Within each of the Forum's four themes, participants discussed two key questions:

- What are today's best practices and research findings?
- What issues need more attention in the future?

Research-Based Advances for STEM Schools

What research are participants building on?

Across the different sessions, leaders referred repeatedly to a collection of research-based concepts and approaches for improving STEM learning. Project-based learning is a strategy where students learn as they tackle an extended project, often around a driving scientific or engineering question. Research and inquiry experiences are often at the heart of new learning opportunities enabling students to engage first hand in scientific processes and practice. Authentic contexts were often featured, enabling learners to more closely engage with concepts in a real-world or realistic scientific setting. Visualization, simulation, modeling, and representational tools were often designed specifically to engage learners in developing conceptual understanding. Learners were often engaged in making or creating something tangible as a pathway to developing their understanding of concepts and skills in STEM. Argumentation and other discursive practices were often featured in the processes of teaching and learning.

What kinds of evidence support this work?

Researchers working on improving the quality of STEM learning opportunities use a variety of research methods, appropriate to the research questions they are asking and the stage of research and development they are engaged in. Some research, as described in the plenary session, seeks to evaluate the impact of a broad policy, such as the policy of inclusive STEM schools, by examining outcomes (e.g., students' course-taking patterns, achievement, interests, career aspirations, sense of self-efficacy) and employing quantitative, statistical analytic methods. Other research seeks to estimate the effectiveness of novel curricula, technologies, teacher professional development approaches, or interventions that combine these elements. Some research designs compare student achievement outcomes in control and treatment groups, which can be statistically matched or assigned randomly. Policy research also seeks to refine understanding of the logic or theory of action of related programs to determine what program features are most important. The Forum also prominently featured design-based research and implementation research projects, where knowledge is generated as a team iteratively improves a design through frequent cycles of designing, implementing, testing, and refining an approach. Design-based research can generate rich knowledge of design features and processes that ultimately improve a program. Finally, many programs represented at the Forum included an element of self-examination, as program developers and leaders shared the insights they had garnered over many years of program implementation. The complementarity of their reflections, arising from the different types of research questions, methods, and programs that were represented, brought a great richness to the Forum.

What new research questions and issues need additional attention?

Across many sessions, Forum participants noted the need for new assessments of student learning that can more faithfully measure the intended knowledge and skill outcomes (e.g., computational thinking at a middle school level) or capture the communicative, creative, or practical use of STEM knowledge. For example, available assessments tend not to be strong in measuring critical thinking, and yet many programs aim to increase critical-thinking skills.

Research on how to integrate multiple aspects of STEM teaching and learning into instruction is also a pressing topic. The Next Generation Science Standards call for implementing three dimensions of science learning (practices, crosscutting concepts, and disciplinary core ideas); more generally, educators are concerned with how to integrate pairs of STEM domains, such as computational thinking and science learning.

Many presenters noted a similar need to revisit the content and approach to teacher professional development. As intensive STEM schools seek to incorporate innovative curriculum, the demands for changes in teaching practice are often high. Likewise, as schools reach out through partnership models, teachers need professional development to understand how to integrate and leverage these relationships. Research in this area is complex, and more attention is needed to methodologies for analyzing education as a complex system. A related need is for the field to become more precise about what it means by constructs such as motivation, interest, and engagement, and how these constructs can be connected to other desired outcomes of STEM schools. Presenters cautioned that while technology-mediated advances can be powerful tools for teaching learners the complex skills needed to solve complex problems, they can also be prone to perpetuating some of the same stereotypes around who can succeed at STEM that students confront in face-to-face learning contexts.

Multiple Stakeholder Communities Around STEM Schools

Which stakeholders have been involved in this work?

Forum presenters shared and discussed the contributions of an impressive range of stakeholders from multiple STEM learning contexts—inclusive STEM schools, other schools with a STEM focus, and schools without a particular STEM focus; multiple types of postsecondary institutions, including community colleges, public universities, and private universities; and informal educational institutions, such as community centers, libraries, and museums. Some projects specifically focused on urban settings, and others on rural settings.

Industry partnerships were a strong feature of much of the work presented at the Forum, and policymakers were featured as well, particularly in the opening and closing plenary sessions. However, most presenters were either research leaders or school leaders; in the future, balancing presentations to feature representatives from different stakeholder communities could be desirable.

What kinds of relationships support this work?

Many discussions at the Forum emphasized that the types of institutional relationships needed depend often on the model of an organization's relationship with learners. Sessions highlighted mentoring relationships; mentors often come from a community, university, or industry setting but serve learners in an educational setting. Long-term relationships between mentors and students were frequently mentioned as particularly important and beneficial. Other kinds of relationships were also seen as beneficial to STEM learning. Many projects had an internship or place-based learning component, where students learn through immersion in a setting outside their educational institution, which often gave students access to a combination of equipment, coaching, and meaningful intellectual work. In other cases, projects leveraged non-school organizations for input on the design of authentic challenges. Complementary to this was the notion of practitioner externships with industry, which build practitioners' capacity to support career exploration and classroom learning of work-based skills. Similarly, increasing emphasis has been placed on the importance of research-to-practice partnerships, such as NSF's Research Experiences for Teachers (RET) program. Engaging stakeholder communities was also seen as critically important in sustaining funding for these efforts.

Which additional stakeholders are needed?

A broad consensus among participants was that the representation of multiple stakeholders at the Forum contributed to the perceived success of the event. And yet, participants also strongly believed that more depth of representation was needed in future events from practitioners, community and industry representatives, policymakers, and other funders so that the key challenges facing Next Generation STEM learning could be more fully discussed from a broad range of stakeholder perspectives.

Social Justice, Equity, and Excellence in STEM Schools and Communities

How do projects frame the equity challenge?

The great majority of schools and projects represented at the Forum framed equity as a social justice issue. They are working to increase the availability of and access to innovative STEM experiences specifically targeted to broadening the participation of youth from groups traditionally underrepresented in STEM fields. Thus, in every session, conversations focused not only on how to increase successful participation in STEM, but also on how to make STEM schools more intentionally inclusive of all students and how to broaden access to high-quality STEM experiences beyond inclusive STEM schools. Both researchers and practitioners talked about access to STEM as a social justice issue: Students from all backgrounds deserve access to STEM, and when students actively engage in STEM content, they often do so through a social justice lens, not just as an academic exercise. In addition, the Forum highlighted the notion that equity and excellence are inseparable and that broadened participation in STEM is vital to maintaining our nation's competitive advantage in a global economy.

How is equity being addressed?

Some sessions focused on how inclusive STEM schools are explicitly working to target students who might not otherwise be interested in or have access to STEM learning, while other sessions shared ways to bring STEM experiences to other settings that are not explicitly STEM-focused. Inclusive STEM schools provide a particularly rich environment for promoting positive STEM experiences, but other contexts can also be points of access for students. Access was identified as only one aspect of equity—inclusive STEM schools also need to look carefully at how their designs and strategies encourage broadened participation through alternative ways of thinking about motivation, engagement, and persistence, with a focus on social and emotional support. Equity needs to be addressed with targeted strategies that align with the local context and realities of the learners, whether geographic (e.g., experiences of rural learners), social (e.g., experiences of girls), or experiential (e.g., experiences of learners of color or students with disabilities). At the same time, strategies that are explicitly aligned to broadening participation in STEM also improve STEM experiences for all students.

What are the most important equity challenges to pursue going forward?

In addition to the overarching and continuing need to refine policies and practices to provide greater access to high-quality STEM experiences (e.g., qualified teachers, challenging curricula) for underrepresented groups, Forum participants noted challenges specific to different youth experiences and different aspects of STEM:

- Learners with disabilities should be active participants, rather than passive users, in the design of assistive technologies
- Technology itself can present limitations for students with disabilities that need to be addressed
- Access and universal design for learning practices need to be integrated into the core of all STEM work
- All students, not just youth with a driving interest in STEM, have the right to and need for increased access to K–12 STEM content in order to promote STEM curiosity and a STEM-literate society
- Computer science and computational thinking specifically need to be part of the K–12 curriculum, and all teachers need access to opportunities to increase their expertise in these areas
- Practitioners need to reach across institutional boundaries, which includes connecting experiences in and out of school, coordinating between K–12 and higher education (particularly for students who arrive at college in need of remediation), and designing and implementing complex interventions across institutions

Scale and Sustainability

How are projects progressing toward scale and sustainability?

As a sector of the economy, education has some of the least developed pathways for moving an innovative and effective approach from its initial conception toward scale and sustainability. In the work of almost every project discussed at the Forum, scale and sustainability were top-of-mind issues. The projects represented are well beyond the basic science or innovation proof-of-concept phase. Indeed, almost all have put considerable work into conceptualizing their approach so that it can scale. This conceptualization often included developing a clear mission, using clear and accessible language for engaging people in the project, refining key project components for re-use in multiple settings, understanding key resource constraints, developing human capital, and arriving at a clear logic model or theory of action for the approach. Beyond this, many projects have shown demonstrable success at scale, and many have been sustained for five years or more beyond their initial round of funding. Key approaches used by the projects include the following:

- Designing for scale and sustainability from the beginning
- Integrating novel resources or programs into existing institutions or common resources
- Promoting a strong focus on long-term partnership development

For programs that strongly leverage technology, the inherent scalability of software-based resources is an advantage. Nonetheless, scale and sustainability remain very difficult challenges.

- Schools frequently change leadership or staff, and programs may not be sustained when personnel changes occur.
- Innovative programs for STEM learning often stretch conventional roles for practitioners and require new pedagogies; as a result, professional development is often key to scale and sustainability.
- Sustaining partnerships across diverse institutions is intrinsically challenging.
- Funding is often more readily available for elements of a program that will be newly designed or evaluated; it is more difficult to obtain funding for those elements that are already successful and yet need to be carried forward.

What approaches to scale and sustainability show promise for the future?

Some projects are beginning to engage in a collective impact approach (Mourad, 2015; Tingley, 2015). Participants identified a strong need to change teacher preparation so that new teachers have more of the skills needed to achieve excellence in facilitating Next Generation STEM learning. Attendees also saw important opportunities emerging to have an impact in the wake of states' and schools' adoption of new curriculum standards, such as the Next Generation Science Standards, which are creating a strong demand for innovative approaches and provide a broader policy framework into which specific resources and approaches can fit.

Participants noted that a more diverse set of large-scale funding resources is emerging, moving from a model where the federal government is the major funder to a model with balanced government, philanthropic, and industry resources—yet it remains difficult for leaders in Next Generation STEM School-related initiatives to find a path among these resources. Hence, participants generally sought more opportunities to convene diverse stakeholders (including educational institutions, policymakers, innovators, researchers, and funders) to discuss the pressing issues of scale and sustainability and seek new paths forward.

Toward the Future

Forum attendees—at the event and in follow-up conversations with presenters that were organized by STELAR, CIRCL and CADRE—highlighted some key next steps for the research and practitioner community in addressing Next Generation STEM Learning for All:

- Presenters and attendees valued the opportunity afforded by the Forum to share research, programs, and practices across disparate stakeholder communities. Many encouraged Forum organizers to consider creating a stream of such events around curated research-based advances in order to continue the conversation. The Forum highlighted the crucial importance of iterative design—articulating, testing, and refining new strategies for broadening participation in STEM learning—while maintaining a dual emphasis on developing the next generation of assessments in order to assess both progress and impact. Further, organizing similar events at existing STEM schools would enable participants to see what successful, next-generation STEM programming "looks like" on the ground.
- A resounding theme across the sessions, and inherent in the conceptualization and planning of the Forum, was the importance of building sustainable, synergistic relationships across multiple stakeholder communities, including those individuals and organizations not often at the table. Both Forum organizers and participants championed collective impact as a framework for partnership building with an outside-the-box approach to identifying and pursuing collaborations.
- Creating high-quality STEM learning experiences for all beyond inclusive STEM schools demands attention to the issues and challenges of equity and social justice.
- New models for scale and sustainability are needed—models that must be conceptualized early and built into the design of new programs and approaches.

Both the Forum and the White House event on STEM High Schools served to underscore the importance of the Administration and President Obama's support of inclusive STEM high schools. The Forum was successful at starting an important and much needed conversation on the next generation of STEM learning among diverse stakeholder groups committed to achieving both scale and impact. There remains energy, engagement, and opportunity from the event to continue this conversation and to realize a bright future for STEM education in our nation.

Summaries of Forum Sessions

The Forum included a plenary panel and 12 concurrent sessions, each of which is summarized below.

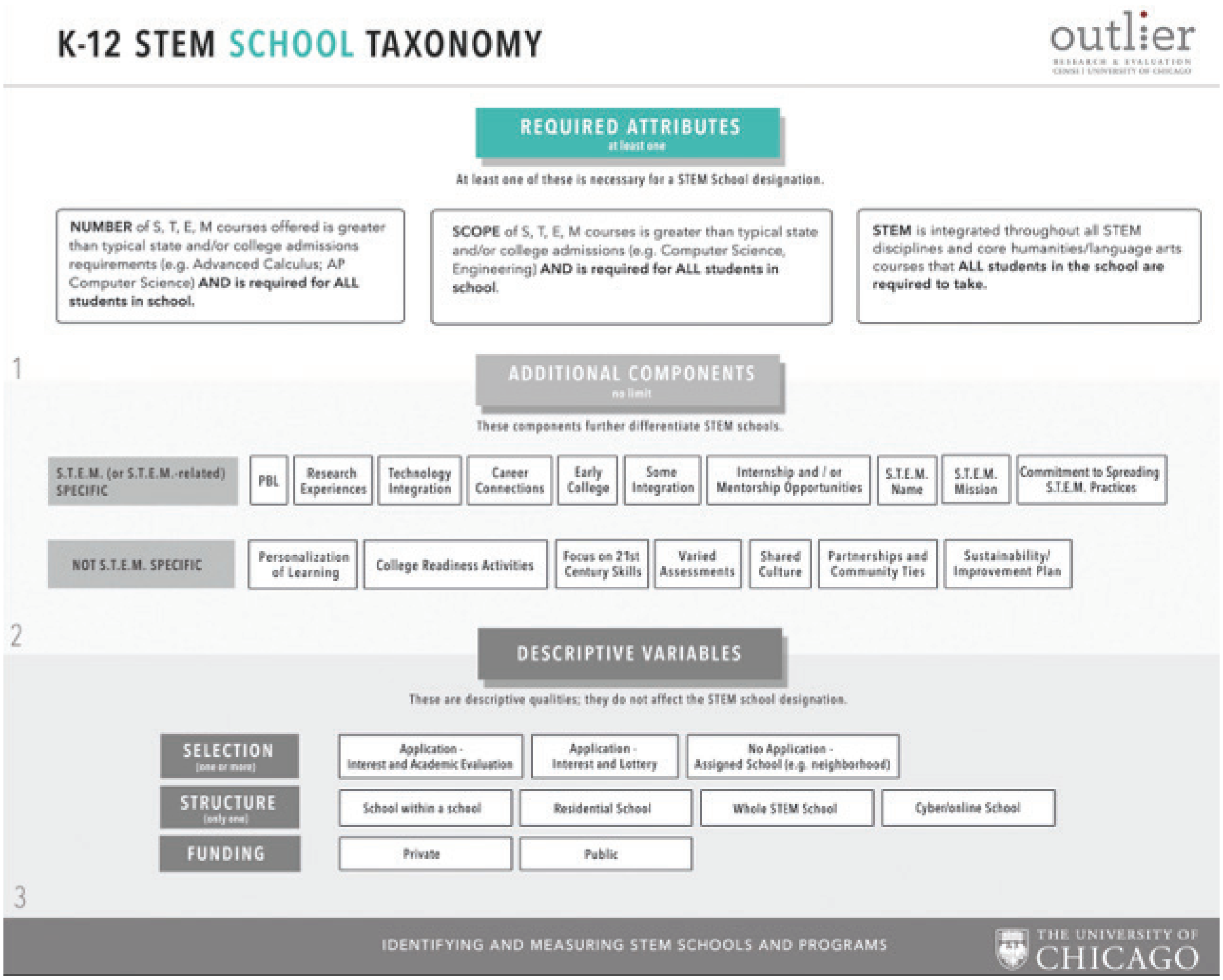
Plenary: Envisioning STEM Schools

What are inclusive STEM schools, and does this approach have transformative potential?

The plenary session brought together researchers and leaders involved with inclusive STEM schools—those that are open to students regardless of their prior grades or coursework (unlike selective schools, which accept students based on prior achievement) and distinctively emphasize STEM learning. Presenters agreed that STEM schools intensify students' engagement in STEM learning and are willing to break the mold of conventional instruction in order to do so. Project-based learning and other integrative approaches were common themes across presentations about STEM schools. Brett Peterson, director of High Tech High, said, "We have a common intellectual mission. The issue is not how to get more AP courses; the solution is to get rid of AP and move to a more integrated model." In a further example of integrative approaches, Metro High School organizes subject matter into four themes: bodies and medicine, digital and media, design and engineering, and growth and agriculture. Stephen Zipkes of the Global Project Based Learning Academy emphasized tackling barriers to success for students traditionally underrepresented in STEM by doing more than offering additional science courses, instead tackling the key STEM issues of social justice (S), teacher quality (T), engaging curriculum (E), and making a difference (M). Zipkes said, "What are the three R's? Rigor, relevance, and relationships—but it's backward. It's about relationships first, then relevance, and then the rigor gets in there." The Chicago High School for Agricultural Sciences, established in 1985 before STEM was even a commonly used term, organizes STEM learning around agricultural topics and exemplifies possibilities for sustainability. However, some leaders of newer inclusive STEM schools indicated that scale and sustainability were still important and ongoing challenges. Further, scale must be defined broadly, to include geographical spread and expansion from high school to earlier and subsequent grades, and from STEM-focused schools to all schools that teach STEM.

The research-based presentations further defined inclusive STEM schools and assessed their transformative potential. Jeanne Century, University of Chicago, presented a graphic (see Figure 1 on next page) that organized required attributes, additional commonplace components, and key ways in which schools vary.

Figure 1. K-12 STEM School Taxonomy



The required attributes included greater availability of STEM offerings, a requirement that all students tackle challenging STEM coursework, a scope that goes beyond state standards, and an emphasis on integrating STEM across courses. In addition to project-based learning, STEM schools often emphasize communication, career preparation, and personalization of learning. Sharon Lynch, George Washington University, studied a large number of STEM schools and found that they also emphasize (1) an intensive STEM curriculum; (2) a teaching staff that is specifically prepared to teach STEM; (3) an administrative structure that is mission-driven, collaborative, and flexible and allows for high teacher autonomy; and (4) the provision of specific supports to help underrepresented students succeed. Lynch also found clear evidence that the schools can produce better outcomes and can scale. The success of a STEM school does not follow from a single course or teacher, but rather from students' systematic immersion in STEM. Barbara Means, SRI International, presented results from evaluation research, which found that after controlling for prior achievement and other student background variables, inclusive STEM schools produce graduates who took more advanced STEM courses and who had better grades, modestly higher achievement scores on some measures, a strong science identity, greater science interest, and greater STEM career interest.

Overall, presenters saw inclusive STEM schools as a clearly successful and scalable model for broadening STEM participation to include more students traditionally underrepresented in STEM. However, sustaining and spreading this model to achieve national impact would require further attention to building connections beyond local successes as well as strengthening the use of an empirical knowledge base to guide efforts to spread, scale, and sustain inclusive STEM practices.

Instructional Materials for Ambitious STEM Teaching and Learning

Research and development have created design principles for instructional materials and approaches that enable all students to learn rigorous and ambitious content, such as computational thinking, algebraic thinking, and K–12 engineering and scientific reasoning. How can research-based knowledge about equity, efficacy, and scaling up contribute to Next Generation STEM Schools?

Ambitious STEM teaching and learning means enabling students to learn foundational disciplinary concepts and skills, going beyond the facts and routine procedures often emphasized in school. The cognitive challenge is to transform "difficult to accessible," and the affective challenge is to transform "boring to exciting"—and presenters shared research findings on how to do this. For example:

- Rigorous research has found that all students can develop deeper conceptual understanding when they control visual representations that change in time.
- Students learn more deeply when they work on tasks that focus on explaining phenomena or on designing solutions to problems, and when they can learn from failure and redesign.

Engineering design can thus be an empowering context for the other STEM disciplines: mathematics, science, and technology. Researchers have also found that the best approaches for teaching STEM directly address student diversity: "Teaching STEM for diversity is teaching STEM for all." A critical element of teaching for diversity is to start early to help students learn the academic language of specific disciplines. A research-based approach to curriculum should start with discussion, modeling, creating explanations, and argumentation, and should directly address students' difficulties in working with complex texts. Discourse should not be seen as an "advanced application" of scientific knowledge, but rather as essential to learning science from the beginning. Research also finds that scaling up while achieving efficacy and addressing equity requires looking beyond "single factor" solutions to approaches that integrate changes in curriculum, technology, teacher professional development, assessment, school leadership, and even the amount of time allotted to courses in the school day. Research has demonstrated that all students can learn science more deeply, but the approaches that work are comprehensive and integrated ones. When ambitious teaching of STEM succeeds, researchers have found that students can be deeply empowered.

The research discussed in this session offers a strong knowledge base that school innovators can use to design effective approaches to ambitious STEM teaching and learning. At the same time, researchers need to continue to improve the usefulness of the base of rigorous evidence about ambitious STEM teaching and learning. For example, individual factors that support ambitious teaching need to be tested in combination, and greater emphasis needs to be placed on how findings from this research can be designed into interventions that scale.

Learning Across Contexts: Rethinking Time and Space for Teaching and Learning

How can design activities, media construction, digital games, and other novel approaches lead to greater student engagement in STEM and improved learning outcomes?

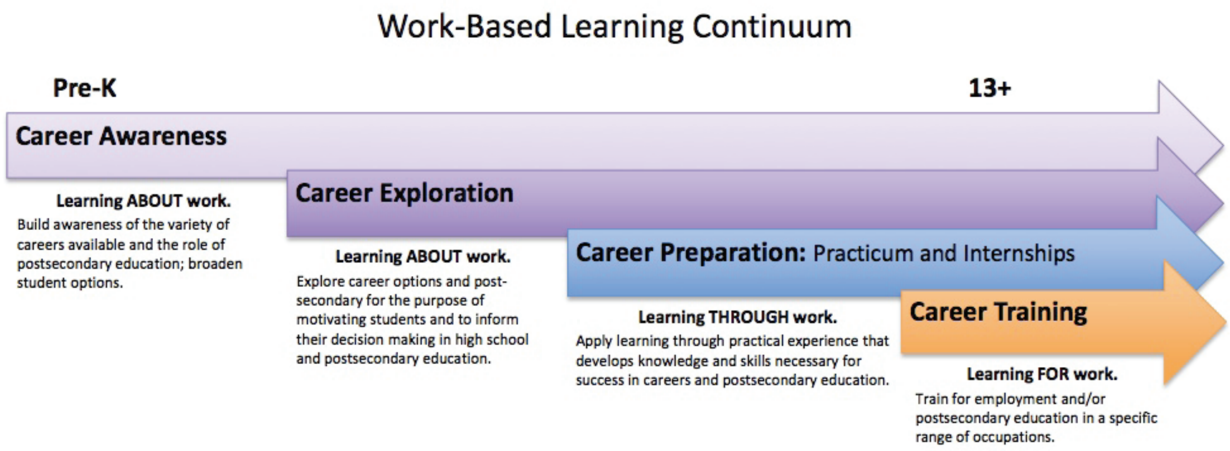
Presenters in this session posited that makerspaces (community-operated spaces where people can gather to create, invent, and learn) provide an opportunity for students to redefine inquiry and participation in learning experiences. Making or creating something tangible allows students to address pressures and challenges in their lives; it makes STEM relevant, broadens their participation in STEM, and increases their interest and self-efficacy in STEM. Game-based learning, geocaching, electronic textiles, virtual reality glasses, and other digital devices can also be useful for the development of complex skills; they engage students in play as a form of learning. In digital environments, embedded assessments such as digital logs elucidate interactions with content and demonstrate how students are learning through exploration, making connections, and thereby making meaning. Common characteristics across effective STEM programs that are employing novel approaches included near-peer mentoring (mentoring by those who have recently gone through experiences that others now or soon will face), empowering learners, making STEM relevant to learners' lives, interdisciplinarity (combining two or more academic disciplines into one activity), and the fostering of a supportive community for both practitioners and learners. All presenters concurred that considerable professional development is needed to enable practitioners to effectively employ these approaches and technologies in formal and informal settings.

Engaging Students in Authentic Discovery and Innovation

How can time and space be re-imagined to engage diverse students in authentic STEM discovery and innovation in and across formal and informal education contexts?

Authentic learning experiences have benefits across learning environments. They change the way that learners think and solve problems by empowering students to be designers of their own learning experiences and producers of content. Real-world, culturally relevant problems ground what learners are learning in the challenges they face in their own lives and communities and help to engage a broad diversity of young people. When connected to career exploration, these experiences can counter students' inherent stereotypes, particularly among populations most underrepresented in STEM, regarding who can succeed in STEM, and they help build students' awareness of viable career pathways. WestEd's Svetlana Darche presented a graphic of the work-based learning continuum that illustrates the importance of career awareness and exploration, as well as the hands-on aspects of career development, such as career preparation and career training (see Figure 2).

Figure 2. Work-Based Learning Continuum



There was general consensus among presenters that developing multi-stakeholder partnerships across groups including business, state and local government, community-based organizations, and higher education, is key to developing strong, authentic learning experiences that will most effectively leverage technology and other tools and engage students. All presenters concurred regarding the need for considerable professional development for practitioners in both formal and informal learning environments, and noted that district curriculum, standards, and testing can be barriers to teachers' ability to successfully implement authentic experiences in the classroom.

STEM Research Experiences for Teachers

How does the NSF Research Experiences for Teachers (RET) program actively involve K–12 teachers in STEM research, and how can these experiences contribute to new forms of professional learning for teachers and other educators?

Four pairs of teachers and academics jointly presented reflections on their experiences in NSF's RET program. Through RET, teachers have the opportunity to participate in research with a university partner and then take those experiences back to the classroom. One speaker noted that RET is intentional professional development for teachers that begins with teachers doing research—but teachers then do much more; for example, they may work on curriculum design, innovative pedagogy, career awareness, and how to talk to students about engineering. Teachers become part of a professional community of problem-solvers, which changes the way they see themselves and their profession. STEM is made more real for them, and they are able to transfer this perception to their students. Presenters agreed on the need to reach out and build more partnerships; one pair described how their work takes advantage of local industries to see STEM careers in a local context, expanding RET beyond university-school partnerships. One current limitation is that rural schools have fewer opportunities to participate in research experiences such as RET.

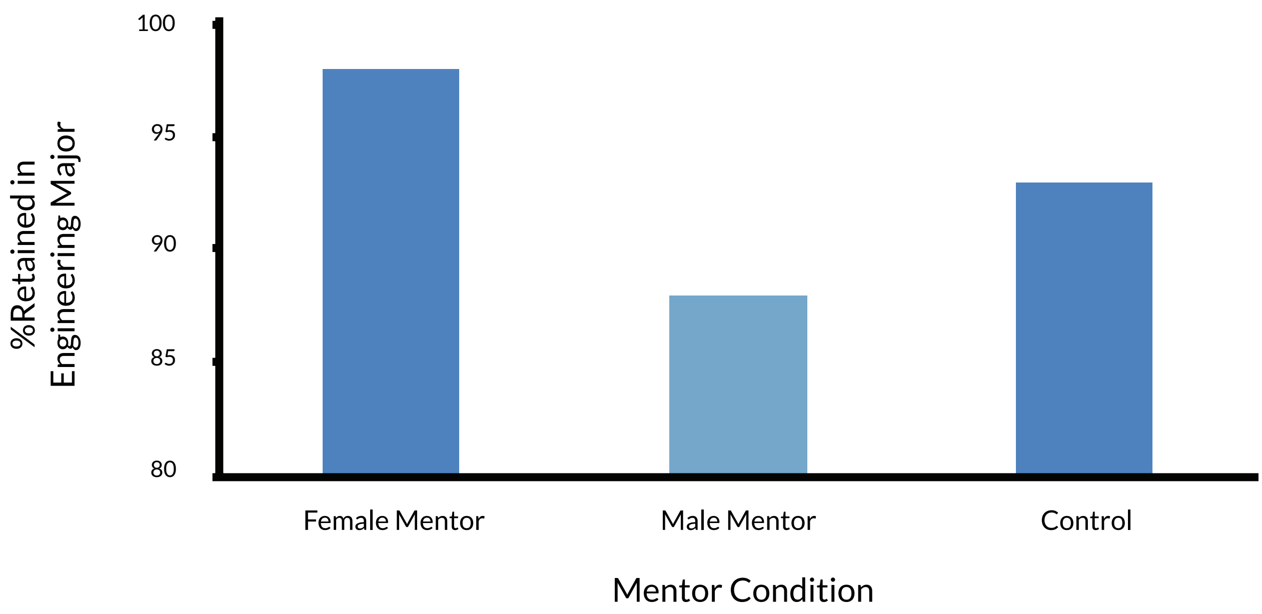
Peers, Mentors, and Messaging: Broadening Participation in STEM

How can we create learner-centered climates that open up new opportunities to take part in STEM?

A key focus of this session was mentoring and messaging. Each speaker described successful mentoring models, including providing credit to college students who mentor high-schoolers, developing social vaccines (actions that address the social determinants and social inequities that are precursors to the problem in question) by pairing female students with female mentors during key transitions in their education, having those outside of the school setting mentor students virtually, and sharing self-mentoring strategies with students. One speaker noted the importance of providing mentors at key transition points, whether from middle school to high school, or from high school to college. Mentoring plays multiple roles for students, including providing them with needed information to be successful in STEM, such as recommended course sequences. Noted one presenter, "If kids aren't taking the courses they need to get ready for STEM in college, then it weakens the impact of other kinds of efforts."

Multiple speakers noted the importance of mentors for girls, and described how "contact with female experts and peers acts like social vaccines." Nilanjana Dasgupta from University of Massachusetts, Amherst, presented results from a study on peer mentoring in college with first-year women students in engineering where female students were given a female mentor, male mentor, or no mentor for one year and then tracked until graduation (Figure 3). Female peer mentors increased the retention of women in engineering majors.

Figure 3. Female Peer Mentors and Retention of Women in Engineering Majors



Mentoring has positive effects for the mentors as well: "Women who mentor get more excited and engaged." One speaker described virtual mentoring, which increases access to mentors for students with disabilities through universal design for learning. Another speaker described developing mentoring ecosystems, which conceive of the whole university as a mentor—administration, staff, and everyone else on campus, not just professors.

Taking advantage of both social media and multimedia technologies for messaging was another key point raised by speakers. For example, messaging is a way to foster excitement around the study of math, challenging perceptions that math is "too hard" or "boring." However, presenters also noted the need to address new barriers to participation that technology creates, such as girls being threatened on gaming sites.

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The discussant pointed out that all the mentoring efforts described are bringing together formal and informal learning, and noted the importance of mentoring and messaging through high school as a way to encourage not only STEM careers but also a STEM-literate citizenry.

Assistive Technologies for Learning: Broadening Participation in STEM

Technology has propelled personalized learning for students and has expanded our ability to understand and address disability-based differences in STEM education and workforce participation. How can these approaches become broadly integrated into Next Generation STEM Schools?

This session focused on the experiences of people with disabilities and the innovative assistive technologies that contribute to a learner-centered climate, not only for students with disabilities but for all students. Speakers addressed ways that these technologies and approaches can become broadly integrated into Next Generation STEM learning. In considering the role of technology in increasing access to STEM learning, one speaker noted that technology should not be assistive and specific to a particular task, but rather should be universally accessible, which can lead to benefits for all students: "If you change your instruction to meet the needs of deaf and hard of hearing students, or any student with disabilities in the class, you will find that all students in the classroom will benefit."

Assistive technologies improve access in multiple ways; for example, tablet apps that encourage interactivity can provide access to STEM content that students with disabilities could not previously access. There is also work being done to identify and address ways that existing technology limits access (e.g., coding languages don't lend themselves to current assistive technologies). One speaker noted that people with disabilities should not just be the recipients of assistive technologies—they should also be active participants in the design of what works for them.

One speaker pointed out that although students with disabilities make up more than 12% of U.S. students, this was the only session at the Forum that specifically addressed disabilities. The speaker urged future Forum planners to integrate the experiences of students with disabilities, rather than have just one separate session. As another speaker noted, "Computing fields need more people with disabilities because their perspectives and expertise will spark innovation. It's not just social justice—it's that we need them."

Developing Tomorrow's Cyber-Workforce: Broadening Participation in STEM

How can youth who are traditionally underrepresented in STEM develop the interest, knowledge, and skills relevant to tackling cutting-edge STEM challenges and careers, such as cybersecurity?

As with other STEM careers, there is a gap between cybersecurity job needs and qualified people. One speaker urged people to resist the tendency to "dump more kids in the pipeline," because this could increase the challenges around broadening participation. For example, there has been an increase in the number of students taking AP Computer Science but not in the proportion of traditionally underrepresented students in those courses. Just adding numbers does not address inequities. Another speaker raised a challenge for broadening participation in cybersecurity when interested and motivated students begin college in need of remediation: Can community colleges and universities effectively address this challenge, or are students shut out of certain STEM careers if they have not had adequate high school preparation? There was common agreement that cyberscience, including cybersecurity, needs to expand throughout K–12; teachers need more knowledge of computer science and cybersecurity, they need more knowledge about different career trajectories, and they need to know how to teach computer science to all students. This session considered the conceptualization of a cyberscientist—someone who understands not just computer science, but also the broader picture of how we use the power of computing and cyberspace in our lives, and how to leverage and harness that power.

Schools as Part of Smart and Connected Communities

How can schools contribute to advancing the goals of smart and connected communities, such as improving personal quality of life, community and environmental health, social well-being, educational achievement, and/or overall economic growth and stability?

The perspective of smart and connected communities sees STEM learning as taking place in a context that is broader than a school, and looks to digital communication technologies to enable students to experience learning as coherent across different settings. For example, mapping resources for STEM learning in a rural community (such as a library, small engineering firm, and 4-H club) and using technology to link to national resources can provide rural students with a more extensive and supportive environment for STEM learning. Centering STEM programs in a Neighborhood House (Herrenkohl, 2015) in a low-income urban neighborhood can create a central resource for multi-generational engagement in STEM. In yet another example, an entire community can focus on solving an environmental problem, such as restoring a harbor. One key aspect of smart and connected learning is an emphasis on innovative learning activities, such as tinkering (and making), pursuing student-driven inquiry, using a citizen science approach (where research is conducted by amateur or nonprofessional scientists), and participating in authentic research experiences alongside professionals. Providing social and emotional support is crucial, as is recruiting and training mentors.
A strong emphasis on smart and connected learning also requires partnerships with, for example, political leaders, school leaders, community leaders, and local companies and organizations. Brenda Bannan, George Mason University, included a graphic in her presentation that emphasized the importance of these partnerships to smart city research and development.

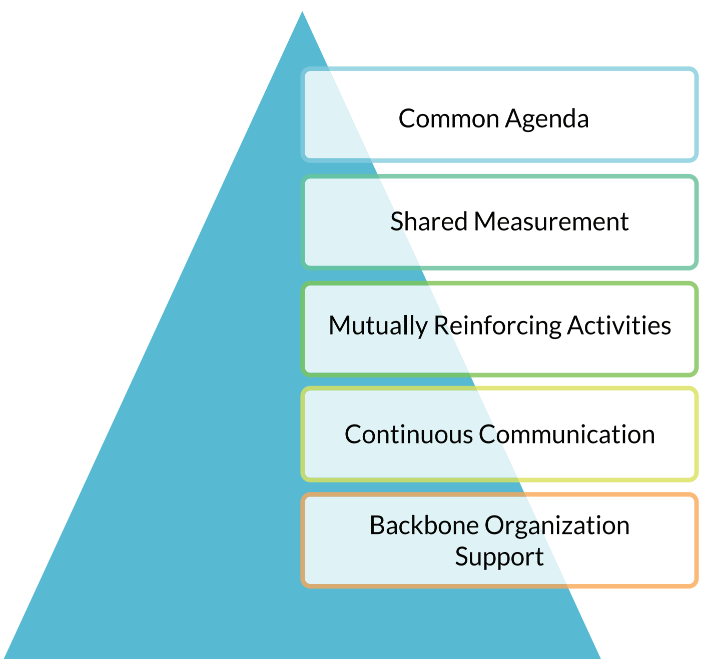
Sustainability is a major challenge for community-based projects, as funding can be unstable, which can make schools reluctant to create a dependence on their broader community. In general, connecting across formal institutions is easier than connecting with informal institutions. A big tension is between the technology- and data-centered views of smart cities (where multiple information and communications technology solutions are integrated to manage a city's assets) and the more people-centered view of learning communities, which place greater emphasis on mentoring relationships, emotional support, and engaging the social capital in a community. It is important to understand the different needs and capabilities of different communities—urban, rural, community-college-based, issue-centric—and then adapt approaches accordingly. Collective impact strategies (where multiple organizations work together toward common goals and metrics, with the explicit support of a "backbone" organization) are attractive for scaling smart and connected learning communities, but this approach is relatively new and requires further exploration, research, and refinement.

Partnerships for Pathways to a STEM Workforce

How can students learn how STEM and other core subject content is applied by real professionals, develop awareness of jobs and careers, experience the challenges of real workplace settings, and begin learning key job skills?

Presenters shared research on pathways and experiences that support students' career- and workplace-focused learning. Each was based on a model of partnership across institutions or settings and included features such as job-shadowing, challenge-based curricula (with challenges based on input from industry partners), scientific field experiences, undergraduate research experiences, summer camps, and mentoring from domain experts. A key finding was that it is important to create opportunities for students to actively work with employers or in more realistic problem-solving situations long before they transition to the workforce. Students need explicit training about what to expect and how to behave in the workplace. Much of the value of these programs is created through the relationships between students and adult mentors, which take time to build. Compared to traditional school tasks, students in these programs experience more relevance, more teamwork, and a greater emphasis on critical reasoning. Some partnership programs are expanding their scale and impact using a collective impact approach, while others approach sustainability through integration into established institutions. Panelists identified three challenges in this area: connecting students' learning experiences across contexts and settings, providing training for teachers so they can leverage partnership-based experiences for their students, and creating a strong liaison between organizations through a backbone organization. Karen Tingley of the Wildlife Conservation Society provided a framework for achieving collective impact, (Figure 4), which was used by her project partnership with universities to diversify the STEM workforce.

Figure 4. Collective impact framework.



Entrepreneurship and Innovation in Schools

How can novel experiences engage students in entrepreneurship and innovation, while supporting their learning of rigorous STEM content?

NSF investigators, teachers, and students are co-creating innovative STEM learning experiences around farming, journalism, bio-manufacturing, making, and modeling. These experiences present an opportunity for students to become engaged in problem solving that matters in a community beyond school and to practice developing innovative solutions. While the "community beyond school" can vary, from a farmers market to a science lab to a media audience, common findings are nonetheless emerging across projects. For example, researchers are finding that an external focus intensifies student motivation to learn science and heightens students' creativity in doing science. An important aspect of learning in these projects is that it centers on or includes STEM communication practices, which can occur through an explicit focus on journalism, an emphasis on creating digital media, or simply through a greater emphasis on storytelling. Although programs differ as to whether they feature entrepreneurial, scientific internship, journalistic, or other community-oriented experiences, all include balanced attention to educational value and external impact. Researchers found that the educational value builds over an extended time period (months or years, rather than days or hours) and can yield greater student interest in pursuing STEM careers.

One key challenge that emerged in the session is that teachers are not presently well prepared to understand how to integrate an entrepreneurial or external impact focus into school-based STEM education, particularly when faced with pressures for students to perform on standardized testing. More broadly, projects of this nature often address many local contextual factors, making replicability in other locations a challenge. Nonetheless, attention to opportunities for an entrepreneurial or external impact focus has strong potential as a feature to be incorporated into Next Generation High Schools.

Advancing STEM + Computing in K–12 Education

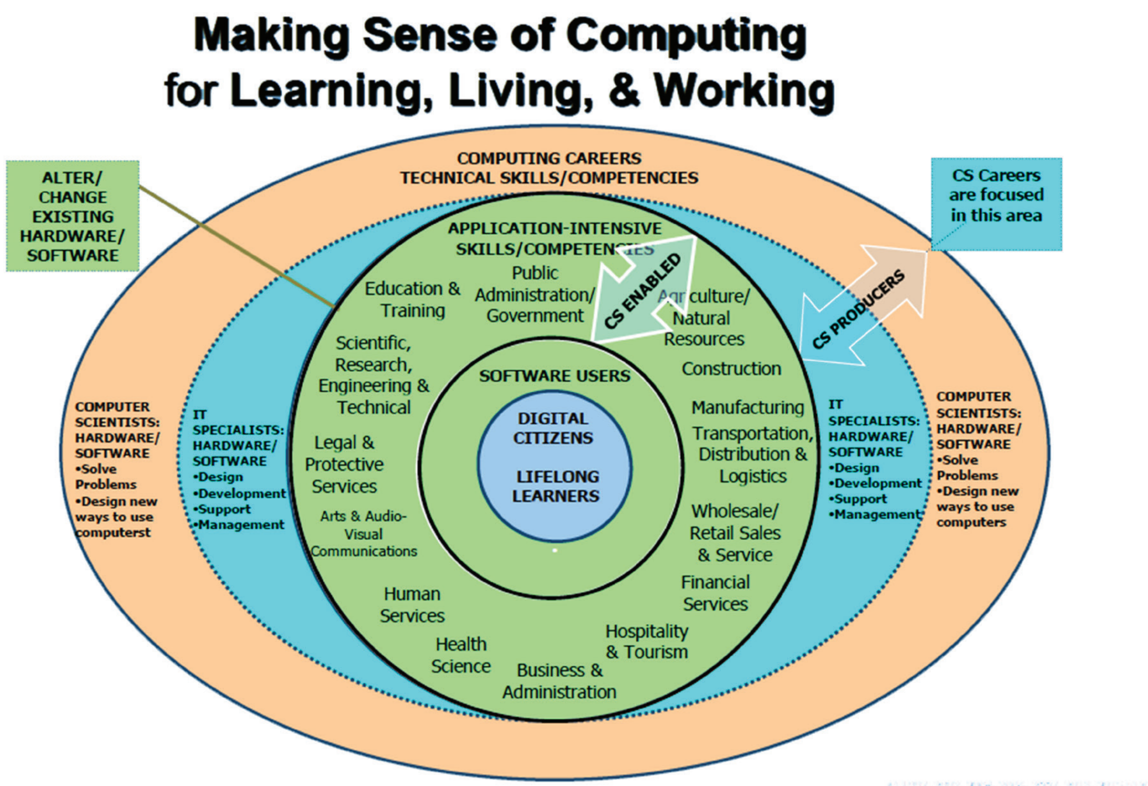
What approaches hold promise for integrating computing and STEM, building a teacher workforce for computer science, and supporting the teaching and learning of computing for diverse learners?

The unifying concern in this session was the longstanding underrepresentation of women, persons with disabilities, African Americans, Hispanics, and indigenous peoples in computing. Early interventions are critical; one speaker noted that among African Americans who obtained a Computer Science Ph.D., more than 90% reported that a K–12 intervention helped them. Using visual metaphors to teach programming can engage women. Another speaker noted that 5–20% of school-age children have learning disabilities, but if needed supports are identified and provided, these disabilities do not necessarily stand in the way of learning computational thinking. Sarah Wille of the University of Chicago's Center for Elementary Mathematics and

Science Education (CEMSE) said that her goal "is to highlight students with learning disabilities as a hidden underrepresented group in computer science."

It is important to help students see how computational thinking is valuable across many subjects and careers; computational thinking and concepts should thus be integrated as a component of the core STEM curriculum, rather than appear only in elective courses. One speaker said, "Computational thinking is not thinking like a computer; it is thinking like a computer scientist." Explicit education about how computational thinking skills are used in careers is necessary alongside teaching the skills themselves, as students do not have an accurate image of how computational thinking is used across the workforce. EDC's Joyce Malyn-Smith presented a graphic (see Figure 5) that illustrates the range of jobs and fields that are enabled by computer science and the importance of producing students that are digital citizens.

Figure 5. The Role of Computing Across the Workforce



Access to computational thinking is a social justice issue, and a major barrier is developing a diverse pool of qualified teachers. One audience member commented that finding ways to assess students' knowledge of computational thinking earlier in K–12 is important. An integrated approach could reach all K–12 students, deepen them as scientists, and expand their job opportunities in the future. However, much research and development is needed on how to meaningfully integrate computational thinking into STEM subjects in ways that attract diverse students.

Cyber-Enabled, Collaborative Learning Environments

Innovative learning technologies transform the use of time and space for STEM learning through virtual reality, augmented reality, collaborative learning, and other cyberlearning approaches. What do we know about how to best use these capabilities to advance STEM learning, and what are the potential risks?

The shift from Web 2.0 to Social 3.0 has brought a sea change in the form of richer opportunities for collaborative learning. With technology's support for synchronous collaboration, students everywhere and anywhere are able to do the same things at the same time, while clarifying their own ideas, hearing new ones, and expanding on others' ideas in unprecedented ways. Virtual immersive spaces, collaborative writing tools, embedded sensors, and other cyber-technologies allow students to think about complex problems and systems that are relevant to them and the communities they live in. Students are designers of their own authentic learning experiences, doing inquiry in the context of real-world problems. They are able to bring personal and contextual information to their evidential reasoning and to connect STEM concepts to their lives in meaningful ways. Partnerships with industry, community-based organizations, and higher education can serve to better integrate learning technology usage across formal and informal settings. However, the process of embracing student-centered and technology-rich pedagogies may take different forms for practitioners; considerable professional development and teacher supports in this area are vital. In addition, presenters in this session cautioned that cyber-enabled environments are just as prone to perpetuating the same gender stereotypes that learners tend to adopt in face-to-face environments, particularly those where males are seen as "expert." It is therefore critical to understand why learners adopt these roles and identify strategies to reduce these patterns online.

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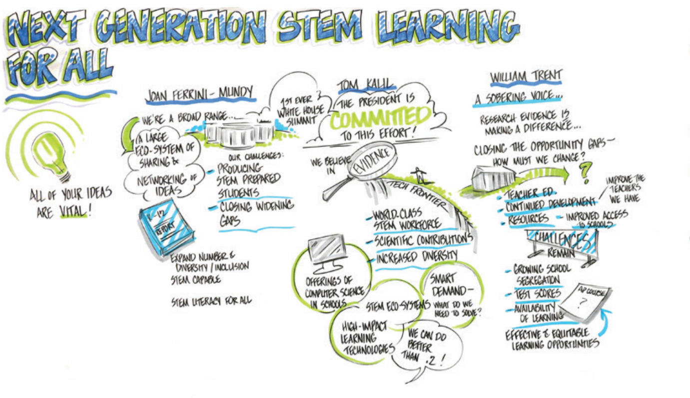
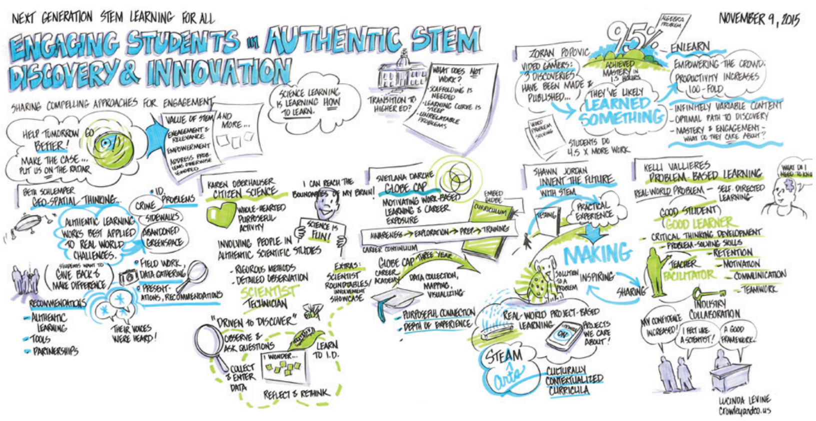

NEXT GENERATION STEM LEARNING FOR ALL
JOAN FERRINI-MUNDY
TOM KALIL
WILLIAM TRENT
ALL OF YOUR IDEAS ARE VITAL!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SHARING COMPELLING APPROACHES FOR ENGAGEMENT
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STEAM
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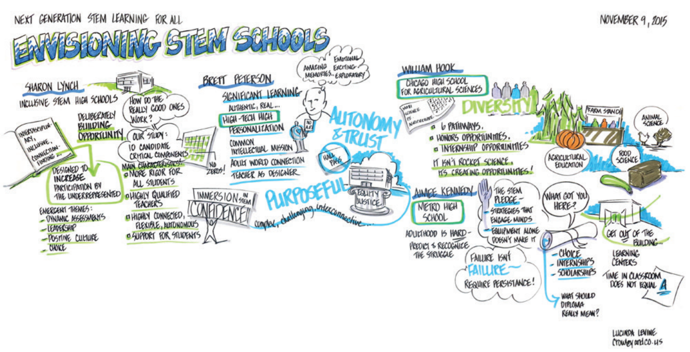
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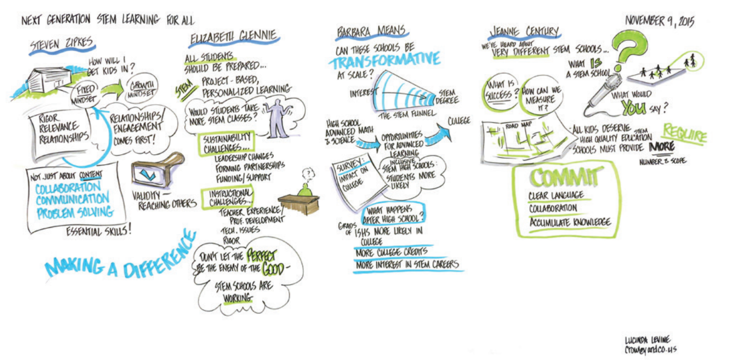
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INNOVATION
FUNDRAISING
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AUTHENTIC ENGAGING RELEVANT
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What is the Most interesting thing you have learned so far?
ENGAGES
Why is research important?
What is necessary to enable students to get a next generation STEM education?
What message do you hope is conveyed
K-12
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