Global STEM Alliance
The New York Academy of Sciences

STEM EDUCATION FRAMEWORK

Research Foundations

Prepared by: SRI International
Center for Technology in Learning | Education Division

Contents

Introduction

The Global STEM Alliance (GSA) STEM Education Framework aims to identify best practices in science, technology, engineering, and mathematics education. It is intended to be used by anyone engaged in STEM education—curriculum developers, content providers, teachers, students, parents, school leaders, policymakers, and philanthropists—to help guide the development and evaluation of high-quality instructional programs and materials.

The framework details 26 features of quality STEM education in three essential areas:

A. **Core Competencies:** To what extent are students provided with opportunities to develop 21st-century skills needed to thrive in the modern workplace? These include seven Essential Skills—critical thinking; problem solving; creativity; communication; collaboration; data literacy; and digital literacy and computer science—and five Supporting Attributes—STEM mindset; agency and persistence; social and cultural awareness; leadership; and ethics—that facilitate and enhance their development.

B. **Instructional Design:** To what extent do the materials and/or program design reflect research-based pedagogy—with an emphasis on project-based learning and real-world application—and a cohesive system of learning objectives, supports, and assessment resources?

C. **Implementation:** To what extent are necessary supports or services available to facilitate distribution and ensure effective implementation? This includes the accessibility of materials, their alignment to local contexts, evidence of effectiveness, and the quality and availability of professional development resources.

This document describes the process used to develop the framework, and points to relevant research literature supporting each element included in the framework.

Development Process

In Summer 2015, the Global STEM Alliance, an initiative of The New York Academy of Sciences with more than 100 partners in 50 countries, collaborated with iCarnegie Global Learning to produce a framework that would offer guidance to designers of instructional programs and materials in science, technology, engineering, and mathematics, and to those seeking to identify sound instructional resources. Drawing on programming developed at The New York Academy of Sciences and input from GSA partners around the world, iCarnegie and GSA staff developed an initial draft of the framework.

In Fall 2015, GSA staff and a team of educational researchers at SRI International convened an international, expert advisory board to direct further review and revision of the framework, and ensure its alignment to current learning science. Board members met throughout December 2015. (See Table 1, below, for a list of members.) Board members offered feedback during collaborative work sessions held via WebEx and phone, as well as through

SurveyMonkey and email. Based on this feedback, SRI researchers led a process of revising the framework, documenting relevant research literature, and developing guidance for the use of the framework.

Jennifer Childress*
Director, Instructional Support, Science
Achieve, Inc.

Katie McMillan Culp*
Chief Learning Officer
New York Hall of Science

Angela Haydel DeBarger*
Senior Program Officer
Lucas Education Research
George Lucas Educational Foundation

John Easton*
Distinguished Senior Fellow
Spencer Foundation

Patrick Griffin*
Director, Assessment Research Centre
Chair of Education
University of Melbourne

Kathy Hurley*
Senior Fellow
P21: Partnership for 21st Century Learning

Mitja Jermol
Head of the Center for Knowledge Transfer in Information Technologies
Jozef Stefan Institute

Krissanapong Kirtikara
Chairman
Council of Rajamangala University of Technology Lanna, Thailand

Jari Lavonen
Professor, Physics and Chemistry Education
Head of the Department of Teacher Education
University of Helsinki

Jia Liu
Dean, School of Psychology
Beijing Normal University

Po-Shen Lo
Associate Professor of Mathematics
Carnegie Mellon University

Chee-Kit Looi*
Professor, Office of Education Research
Learning Sciences & Technologies
Academic Group
National Institute of Education, Singapore

Megan Pacheco*
Chief Learning Officer
New Tech Network

Gabrielle Rappolt-Schlichtmann*
Executive Director and Chief Scientist
EdTogether, Inc.

Linda Rosen*
Chief Executive Officer
Change the Equation

Linda Shear*
Director of International Studies
Center for Technology in Learning
SRI International

Helen Soule*
Executive Director
P21: Partnership for 21st Century Learning

Manabu Sumida
Associate Professor, Faculty of Education
Ehime University, Japan

Sha Tao
Professor, Child Psychology
Beijing Normal University

Claudia Urrea
Lecturer and Researcher, PK–12 Initiative
Office of Digital Learning
Massachusetts Institute of Technology

Table 1. GSA STEM Education Framework Advisory Board

* Denotes Working Group member. These members participated in a series of working meetings to refine an initial draft of the framework, in addition to reviewing the final draft.

Related Literature

The ideas expressed in the framework are supported by learning science and education research. Following are brief research summaries and references for each element included in the framework.

Part A: Core Competencies

A.1 ESSENTIAL SKILLS

A.1.1 CRITICAL THINKING: The mental processes, strategies, and representations people use to solve problems, make decisions, and learn new concepts (Sternberg, 1985).

The importance of critical thinking skills has been underscored across several disciplines including STEM (e.g., social sciences, literature). Critical thinking skills are at the core of science education curricula (Paul & Binker, 1990). The National Science Education Standards (1996) outlined key characteristics of critical thinking, including reaching the most logical explanation based on careful review of existing assumptions, alternative explanations and perspectives, and application of logical thinking as one reviews these along with a critical examination of evidence to reach the conclusion to an argument or solve a problem (Bailin, 2002; Pithers & Soden, 2000). Teachers can use prompts and questions to allow students to reflect on contrasts, parallels, unexplained inconsistencies in the data, and if necessary reclassifying it by challenging prior assumptions (Pithers & Soden, 2000). These teacher initiated strategies eventually help students to put forth data and evidence to support their claim (Pithers & Soden, 2000).

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Sternberg, R. J. (1985). Critical thinking: Its nature, measurement, and improvement. In F. R. Link (Ed.), Essays on the intellect (pp. 45-65). Alexandria, VA: Association for Supervision and Curriculum Development.

A.1.2 PROBLEM SOLVING: Application of prior knowledge and skills (i.e., strategies) that allow persons to tackle a range of new tasks and situations within some performance domain (adapted from NRC 2012, Education for Life and Work: Developing Transferable Knowledge and Skills in the 21st Century, p. 167).

Problem solving is the ability of students to apply their existing knowledge and strategies to develop solutions to new problems and situations. Solving problems is an integral part of STEM education, and has been described as being "at the heart of mathematics" (Cockcroft, 1982). Problem solving can provide tools to engage students in "fun" activities to motivate them to learn, to practice a technique, and even to introduce new topics in mathematics (Schoenfeld, 1992; Stanic & Kilpatrick, 1988). Ideally, math curricula that use problem solving as the pivot for learning should allow students to engage in "reflective inquiry" and require students to undertake the responsibility of providing arguments for their solutions to their peers (Hiebert et al., 1996). Problem solving has a twofold advantage for students, since they are not simply regurgitating or rote-learning math concepts, but instead developing a structural understanding of the concepts, as well as procedural skills or methods to apply those concepts, thus be engaging in overall deeper learning (Hiebert et al., 1996).

Similarly, problem solving is central to the study of science and engineering, where everyday problems can be used as a teaching medium for students to learn concepts (Handelsman et al., 2004). For inherent reasons, problem solving is at the crux of engineering curricula, where students are essentially learning techniques to solve given problems (Chapra & Canale, 1998). The experiential learning nature of problem-based learning is ideal for teaching science and engineering (Xian & Madhavan, 2015).

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A.1.3 CREATIVITY: Use of a wide range of idea creation techniques (such as brainstorming), generation and use of new and worthwhile ideas (both incremental and radical concepts), openness to new and diverse perspectives (adapted from Partnership for 21st Century Skills website materials (www.p21.org).

While researchers have debated the emphasis put on creativity in science education for fear of losing focus on the content students must master, they have largely agreed upon the importance of encouraging creativity and approaching problems from multiple perspectives (Garrett, 1987; Solomon, 2000). As students take on problem-solving activities as part of STEM learning activities, students need to be encouraged to engage in creative thinking and exploration, which requires demonstration of divergent thinking or brainstorming ideas (Plucker, Beghetto, & Dow, 2004). The vast array of current world problems (e.g., climate change, renewable energy, poverty, unequal educational opportunities) underscore the need for creative solutions (Shute & Torres 2012; Walberg & Stariha, 1992) considering the social and economic ramifications for the world's population. Creativity in scientific thinking manifests itself in the form of imagination, visualization and innovation (Comark & Yager, 1989; Kind & Kind, 2007). Individual research projects or project-based learning activities are excellent curricular tools that create opportunities for students to develop and demonstrate their innovative, and imaginative thinking skills (Sawyer, 2011).

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Walberg, H. J., & Stariha, W. E. (1992). Productive human capital: Learning, creativity, and eminence. *Creativity Research Journal, 5*, 323–340.

A.1.4 COMMUNICATION: Effectively using oral, written, and nonverbal communication skills for multiple purposes within diverse contexts (e.g., to inform, instruct, motivate, persuade, and share ideas). 21st century communication skills also include effective listening; using technology to communicate; and being able to evaluate the effectiveness of communication efforts adapted from Partnership for 21st Century Skills website materials (www.p21.org).

Communication skills have long been accepted as being a vital skill set to demonstrate 21st-century readiness skills (Duffy, Gordon, et al., 2004). This includes the ability to use new modes of technology and digital media. Students should also be able to demonstrate their ability to listen well to other students and skillfully communicate their own scientific understanding. They should also be able to share their scientific explanations and ideas through various visual mediums (Bell, 2010; Dede, 2010; Trilling & Fadel, 2009). These may include graphs, charts, illustrations, and scientific debate and argumentation. For each of these, students should be able to effectively communicate assumptions and ideas, evidence, counter-evidence, and effectively present reasoned arguments (Partnership for 21st Century Skills, 2009).

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A.1.5 COLLABORATION: “Coordinated, synchronous activity that is the result of a continued attempt to construct and maintain a shared conception of a problem” (Roschelle and Teasley, 1995, p. 70) and/or “the activity of working together towards a common goal” (Hesse, Care, Buder, Sassenberg, et al., 2015, p. 38).

Collaboration environments that promote peer engagement around content materials are ideal for inquiry-based learning activities. The inherent nature of STEM fields, where scientists and engineers collaborate, underscores the need to engage students in scientific discourse, argumentation, exchange of ideas, and collectively building scientific knowledge (Driver, Newton, & Osborne, 2000; Duschl & Osborne, 2002; Minner, Levy, & Century, 2010). Student collaboration can be encouraged by way of small group work, which includes defining a common goal for the group members, assigning roles to individuals, creating accountability systems, and reflecting on quality of work as a group (Stinger, Stanne, & Donovan, 1999). Various tools have been developed to afford collaboration opportunities to students in computer-mediated and online learning environments, allowing students to co-construct scientific knowledge in digital and hybrid spaces (Brindley, & Blaschke, & Walti, 2009; Curtis & Lawson, 2001; Edelson, Gordin & Pea, 1999).

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A.1.6 DATA LITERACY: Understanding, explaining, and documenting the utility and limitations of data by becoming a critical consumer of data, finding meaning in data, and taking appropriate action based on data, as well as an ability to identify, collect, organize, evaluate, analyze, interpret, present, and protect data (adapted from: *Building Global Interest in Data Literacy: A Dialogue-Workshop Report*, as reported by Educational Design Center - May 4, 2016).

STEM content must be taught in ways that students develop data literacy. These skills may include, but are not limited to, interpreting quantitative and qualitative data, being able to judge when inadequate data are provided, and knowing how to analyze data to generate knowledge, (Ryder, 2001). There is a burgeoning need for STEM professionals across research and industry to analyze, process, and interpret large data sets (Manyika et al., 2011; Perrin, 2015). To meet this growing demand, students need exposure to learn how to engage with both qualitative and quantitative data, including how to problem solve, investigate, and design data sets for inquiry and analysis. At the same time, students also need to be trained in using these data analysis tools in an ethical manner, given privacy and security concerns around access to big data (Manyika et al., 2011).

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Ryder, J. (2001). Identifying science understanding for functional scientific literacy. *Studies in Science Education, 36*(1), 1–44.

A.1.7 DIGITAL LITERACY & COMPUTER SCIENCE: Ability to use information and a variety of communication technologies to find, evaluate, create, and communicate information and collaborate with peers, colleagues, family or the general public; including an understanding of ethics and privacy and computational skills (e.g., abstraction, algorithms, data, programming and development, modeling and simulation) (adapted from ALA Office for Information Technology Policy, ALA Digital Literacy Taskforce (2011; http://connect.ala.org/node/181197#sthash.ZDVRXwGh.dpuf).

Digital literacy can be broadly understood as the "ability to understand information however presented" (Gilster, 1997). In the growing digital environment with new media emerging every few years, this ability is also referred to as being "information savvy" (Fieldhouse & Nicholas, 2008), and includes both information seeking and information handling skills. Learners must be able to use digital environments to gather information and demonstrate critical thinking and knowledge comprehension (understanding information, comparing and contrasting, summarizing), analysis (pattern recognition, organizing and ordering information), application of knowledge for problem solving (generalizing information to new situations, solving problems), and synthesis and evaluation (evaluating evidence and concluding) (Johnson, 2007). Moreover, computer science and computational thinking, he study of computers and algorithmic processes, including their principles, their hardware and software designs, their applications and their impact on society" (Association of Computing Machinery, 2003), is now recognized as an important component of students' academic and career pathways. "Computer science is a lens and an entry into skills in critical and logical thinking that apply across all disciplines, including writing and the humanities" (Carey, 2010).

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A.2 SUPPORTING ATTRIBUTES

A.2.1 STEM MINDSET: Materials support the development of productive habits of mind, dispositions, and ways of thinking and engaging in classroom activities that support STEM learning and problem solving (e.g., evidence-based perspectives).

STEM classrooms need to foster students' ability, willingness, and curiosity to apply knowledge of scientific procedures and methods in flexible ways, and thus "convert knowledge and skill into action" (Bailin, 1999; 2002; Gauld, 1982). Both STEM curricula and instructional practices need to encourage the development of students' critical thinking to support the thoughtful application of inquiry, technical, design, and computational skills (Simon et al., 2006). Students need to be able to analyze data (both from primary and secondary sources), confirm the reliability and authenticity of the data before inferences are drawn from it, and where appropriate examining the evidence against established scientific knowledge. It is also important for students to explore a range of explanations and solutions, and examine the logic and evidence that points to the most scientifically robust argument and model (Simon et al., 2006). These habits pervade all aspects of scientific research and processes, may it be problem solving, engaging in systems thinking to understand the problem, and using a data and evidence driven approach to approaching a STEM problem or goal. The instructional environment should enable and encourage students to explore disciplinary procedures and assumptions, across STEM and non-STEM topics, in ways that encourage creativity and innovation.

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A.2.2 AGENCY & PERSISTENCE: Ability to apply perseverance and passion for long-term goals through sustained and focused application of talent (knowledge, skills, and abilities) over time, even in the face of difficulty or opposition (Duckworth, 2007).

Since the well-received paper by Duckworth et al. (2007) found that grit has a notable predictive relationship with success factors, research has examined how grit or perseverance can be an important noncognitive trait for success in long-term goals (Subotnik et al., 2015). Students' sense of agency can also manifest in scientific exploration and argumentation, both of which are integral features of scientific work. Persistence is manifested with continued effort, and adopting novel approaches to address the obstacles students face during a problem-solving activity. Academic fields like engineering, science, and math often require long-term projects and challenging courses, and some research shows that students have more success in pursuing advanced courses in these subjects if they demonstrate perseverance and success in early foundational courses (Subotnik et al., 2015). There is a growing number of studies underscoring the critical role that academic persistence plays in students' success and continued participation in STEM courses, especially if they belong to groups typically underrepresented in STEM fields (Mau, 2003; Russell, & Atwater, 2005).

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A.2.3 SOCIAL & CULTURAL AWARENESS: Being cognizant, observant, and conscious of similarities and differences among and between cultural groups (Goode, 2001, revised 2006 National Center for Cultural Competence) and "recognition of one's own cultural influences upon values, beliefs, and judgments, as well as the influences derived from the professional's work culture" (Winkelman, 2005, p. 9).

STEM professionals work in an increasingly diverse and globally connected world. It is therefore important that teachers model social and cultural sensitivity and tolerance to their students (Haberman, 1991) and demonstrate understanding the similarities and dissimilarities among cultural groups (Goode, Dunne, & Bronheim, 2006). This skill is important especially in STEM professions such as medicine, where social and cultural values are background contextual factors that can often come to the foreground in the normal course of professional work (Beagan, 2003; Rew et al., 2003) (e.g., being culturally sensitive to patient needs and experiences, language barriers, cultural norms for treating patients of different gender (Goode et al., 2006)).

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Rew, L., Becker, H., Cookston, J., Khosropour, S., & Martinez, S. (2003). Measuring cultural awareness in nursing students. *Journal of Nursing Education, 42*(6), 249–257.

A.2.4 LEADERSHIP: Guiding, managing, or directing another person or a group of people using such skills as consensus-building, decision-making, effective communication, and successful conflict management (Johnson, Johnson, & Smith, 1998).

Leadership skills are important complementary skills for students' social competencies. As students work in teams on projects, they need to demonstrate leadership skills, such as consensus building, decision-making, effectively communicating to and for the team, and managing conflicts (Johnson, Johnson, & Smith, 1998). These skills of building and maintaining team dynamics and demonstrating responsible decision making are integral to academic success (Farrington et al., 2012).

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Johnson, David W., Roger T. Johnson, & Karl A. Smith, (1998). Cooperative Learning Returns To College: What Evidence Is There That It Works? *Change, July/August 1998*, p. 27–35.

A.2.5 ETHICS: Materials explicitly introduce ethics of STEM activities and professional work (e.g., use of human subjects in research).

Ethical norms are integral to how STEM professionals carry out scientific practice (Resnik, 2005; Shamoo & Resnik, 2015) and therefore should be an objective of STEM education. For example, ethical debates impact important national and international policies, such as: genetic engineering, human cloning, secret testing on humans by pharmaceutical or intelligence agencies, and the economic and political ramifications of scientific evidence on global climate change (Resnik, 2005). The range of ethical concerns that scientists and engineers need to pay attention to include a wide range of issues: fabrication of data, restricting criticism of scientific work, freedom to explore any question or hypothesis, plagiarism and failing to give credit, lack of respect for all subjects in scientific research, abdicating their social responsibility to inform the public, failing to follow laws, and inequitable opportunities to pursue STEM careers. Instruction of ethical practices in STEM should include both informal (e.g., modeling by teachers and mentors) and formal (e.g., direct instruction) means of communication (Hollander et al., 1995). Direct instruction allows for students to become familiar with the broad range of ethical concerns in current STEM research and debates.

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Part B: Instructional Design

B.1 RESEARCH-BASED PEDAGOGY: Materials that are supported by current research-based pedagogical strategies and explicitly documents links between research, curriculum design, STEM concepts, and principles of learning (adapted from Bransford, Brown & Cocking, 2000).

Well designed instructional materials draw from current research, document how research influenced design choices, and provide instructors with a “meta-guide” explaining the links between research, curriculum design, and principles of learning (Bransford, Brown, & Cocking, 2000). Those considering using the materials, particularly teachers, need to be able to draw connections between the instructional design principles, STEM concepts presented in the materials, and informed models of learners’ conceptual development. For example, curricula should provide teachers with guidance about prior knowledge students should have, typical misconceptions students may have, and teaching practices to support students’ learning. Moreover, curricular materials that inform and educate teachers of subject matter knowledge, pedagogical content knowledge, and disciplinary practices can serve as cognitive tools that enhance the their teaching practice (Davis & Krajcik, 2005).

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B.2 STEM CONTENT INTEGRATION: Materials present and/or integrate practices and disciplinary core ideas of science, technology, engineering, and/or mathematics content as part of a multidisciplinary approach within a STEM discipline or a non-STEM discipline (e.g., humanities, social science, art). Based on a multi-disciplinary approach, content is aligned to instructional frameworks or local policy initiatives, as a means to connect to local or national economic development efforts and workforce needs.

The goal of STEM education goes beyond students’ conceptual understanding of STEM topics to include evolving their ways of thinking and capacities so they can apply STEM knowledge to purposes beyond textbook application - meeting both personal and the larger community’s needs (American Association for the Advancement of Science, 1993; Bevan et al., 2010; National Academies of Sciences Committee on Science Learning K–8, 2007). Instructional approaches that integrate K–12 STEM topics within the context of real-world issues can make STEM subjects more relevant to students and teachers, thus enhancing motivation for learning and improving student interest, achievement, and persistence (Burghardt et al., 2010; Honey, Pearson & Schweingruber, 2014). Together, these outcomes help address calls for greater workplace and college readiness as well as increase the number of students who consider a career in a STEM-related field. To that end, the presentation of STEM content in an integrated fashion, including contexts that present ideas and activities from multiple STEM disciplines and contexts that link STEM content to humanities, social science, art, and other subjects areas, is seen as a valuable approach (Honey, Pearson & Schweingruber, 2014). This perspective is reflected in both the Common Core State Standards for Mathematics (CCSSM; National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010) and the Next Generation Science Standards (NGSS; NGSS Lead States, 2013), which call for more and deeper connections among STEM subjects in the United States. For example, the NGSS explicitly includes practices and core disciplinary ideas from engineering alongside those for science, raising the expectation that science teachers will teach science and engineering in an integrated fashion.

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B.3 REAL-WORLD APPLICATION: STEM problems and challenges are presented in real-world scenarios in which STEM skills and knowledge would be applied. Curricula makes explicit links of instructional content to real-world problems/situations.

Researchers have found that shifting the focus of the STEM curriculum to problem solving allows students to engage in reflective inquiry, reinforcing students' knowledge acquisition and application and be better prepared to applying their STEM knowledge for higher education and careers in STEM (Hiebert et al., 1996; Hoachlander & Yanofsky, 2011; Kolodner et al., 2003). Students apply their science and math content knowledge to problems embedded in engineering and technology in real life scenarios (such as designing architecture that can withstand earthquakes, or refining designs for pace-maker designs). Both in and out of school students can be seen applying their STEM content knowledge to real-world issues and problems as part of the curricula (Darling-Hammond, Ancess, & Falk, 1995; Hoachlander & Yanofsky, 2011; Kolodner et al., 2003). Some examples include engineering pathway classes where high school students learn algebra and geometry to design architecture that can withstand earthquakes, or using computer programs to apply that math to develop virtual models of the architecture (Hoachlander & Yanofsky, 2011).

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B.4 PROJECT- OR PROBLEM-BASED LEARNING: “Students gain knowledge and skills by working for an extended period of time to investigate and respond to an authentic, engaging and complex question, problem, or challenge” (Buck Institute for Education) including reflection on why they are doing what they are doing instead of just following activity instructions, a collaborative or social component (Blumenfield, Marx, Soloway & Krajcik, 1996), and opportunities for students to reflect on their progress, evaluate their own learning and seek resources to deepen their learning when needed.

Researchers have identified design principles to guide project/problem-based learning (PBL) activities (Barron, et al., 1998; Barrows, 1996; Savery, 2006; Strobel & van Barneveld, 2009). These principles include “doing with understanding” that calls for curricula to engage students for an extended period of time in focused problem solving that involve them in deeper reflective understanding of why they are doing what they are doing instead of just following activity instructions. A collaborative or social component is important to make PBL experiences successful, since students working together toward common learning goals as part of an inquiry allows for creative and reflective thinking (Blumenfield, Marx, Soloway, & Krajcik, 1996). It is important to provide scaffolds to teachers to promote inquiry-driven thinking and help students develop solutions to challenges in activities. These opportunities for students allow them to reflect on their progress, evaluate their own learning, and seek resources to deepen their learning when needed. Furthermore, it is important to have students collaborate on the inquiry project as it requires them to work toward common learning goals, brings in diverse perspectives and opinions, thus allowing for creative and reflective thinking to develop the solutions (Blumenfield, Marx, Soloway & Krajcik, 1996). Similarly, when PBL experiences provide opportunities for instructors to collaborate , it benefits teachers’ instruction as they are able to generate ideas from a collective pool of thinking. The Buck Institute for Education project-based teaching rubric provides an effective self-reflective tool to instructors using PBL based activities for improving their practice both in the short and long-term (www.bie.org).

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B.5 SCAFFOLDING: Teachers are supported to use scaffolds (guidance, resources, assistance) to create a learning environment that is inclusive of multiple learning strategies (e.g., when to move into groups, when to work independently, when to provide direct instruction) that align with the pedagogical strategies of the curriculum (adapted from Riordan & Noyce, 2001).

Curricula can be designed in ways to build scaffolding or supporting structures for both teachers and students using the science curricula. Teachers and facilitators using a new curriculum benefit from detailed curricula that provides guidance for how materials can be adapted to the learning environment and audience (Kauffman, Johnson, Kardos, Liu, & Peske, 2002). Good curricula also lay out ways teachers can adapt the curriculum to their teaching styles or adapt specific steps in the curriculum or lesson to the skill levels of the students, thus providing multiple pathways for students to reach the same goal. Well-designed curricula also provide scaffolding to teachers to help them create a learning environment that is inclusive of multiple learning strategies (e.g., when to move into groups, when to work independently, when to provide direct instruction) that align with the pedagogical strategies of the curriculum (Riordan & Noyce, 2001). Similarly, for students, scaffolding in STEM learning tools allow students to explore problem solving in ways that promotes increasing responsibility and ownership while making continued progress towards their solution (Collins, Brown, & Newman, 1989; Hogan & Pressley, 1997; McNeill, Lizotte, Krajcik, & Marx, 2006).

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B.6 ASSESSMENT: Opportunities for students to generate evidence of their learning over time. Assessments are aligned to the learning goals of curricula activities and provide meaningful and useful information (feedback) to teachers and students about gaps in students' learning so that further instruction and support may be provided to bridge the gaps. Ideally, materials include assessment scoring materials, guidance about using outcomes to make data-driven decisions, and pedagogical strategies to address conceptual challenges identified by assessments.

The most essential purpose of assessment is the feedback it provides to learners and instructors about gaps in students' learning so that further instruction and support may be provided to bridge the gaps. There are various methods for assessment, including paper-and-pencil, online, and oral assessments. Assessments must focus on students' understanding, though it is not critical to require students to provide lengthy responses. Even multiple-choice questions can be used to assess deep learning. However, it is critical that assessments are aligned to instruction. Formative assessments provide frequent feedback about what students have learned and may be struggling with (Black & Wiliam, 1998, 2009). These assessments tools serve as critical tools for instructors to ensure that student learning is progressing on track. They also serve students by providing them markers for their own learning, and allowing them to be more agentic in their own learning and seeking help when their learning falls short of the expectations. Summative assessments provide a more comprehensive view of student learning at certain intervals, generally following an extended period of instruction or intervention. They can tend to be more criterion-referenced (Harlen & James, 2006), as instructors use them to gauge whether students have learned major themes or standards. This is particularly important in areas of STEM where more advanced topics build on previously learned foundational skills; thus for students to succeed, it is important that they demonstrate their grasp of big ideas at each level.

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B.7 CULTURAL SENSITIVITY & RELEVANCE: Materials support teaching methods or pedagogies that explicitly acknowledge, identify, and situate the historical, cultural, political, and social experiences and beliefs of the student as related to the STEM activities and content (Nasir, 2007; Nasir & Hand, 2008; Preece, 2009).

Culturally sensitive teaching methods or pedagogies are critical for teachers and informal learning practitioners who are preparing students for a culturally diverse workforce, and when students bring multiple cultural backgrounds and resources to a learning setting or scientific inquiry (McGee Banks & Banks, 1995). Research focusing on the learning experiences of African-American students has underscored the importance of building cultural competence among teachers so they can in turn maximize the learning experiences of their students (Ladson-Billings, 1995; Tate, 1995). Students are more likely to learn STEM content and identify as a STEM learner if the content they are learning is salient to their individual identity and their cultural and social experiences and beliefs are valued as part of the learning experience (Nasir, 2007; Nasir & Hand, 2008; Preece, 2009). This is critical to ensure students can bring their unique perspectives that connects to their local community into their inquiries and work that they will do as adults in the STEM workforce. This principle of culturally sensitive learning becomes more pronounced when STEM curricula are transported from contexts in which they were designed to new settings where cultural assumptions may not match (Lekoko & Modise, 2012).

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B.8 TECHNOLOGY INTEGRATION: Materials support the routine and transparent use of technology to support curricular goals and deepens and enhances the learning process (adapted from Edutopia http://www.edutopia.org/technology-integration-introduction).

STEM professional activities are increasingly technology-dependent, and learners must be able to use digital tools as part of the curriculum. Technology can be used to gather information and demonstrate knowledge comprehension (understanding information, comparing and contrasting, summarizing), analysis (pattern recognition, organizing and ordering information), application of knowledge (generalizing information to new situations, solving problems), synthesis and evaluation (evaluating evidence and concluding) (Johnson, 2007). Technology can enable students to actively engage in the learning process (Bai, Pan, Hirumi, & Kebritchi, 2012; Zucker, & Light, 2009). The ability to use advanced computing and telecommunications to solve real-world problems is integral to 21st century skills. For instance, curricula can require students to use simulation and visualization tools to identify patterns, conduct dynamic modeling of data, and developing logical reasoning skills (Dede, 2000). Importantly, technology is an effective tool for encouraging collaboration among students (Bingimlas, 2009; Osborne & Hennessy, 2003). Despite challenges for integrating technology in school curriculum remain (e.g., lack of access to technology) attention should also be paid to developing teachers' pedagogical approaches with the use of technology and increasing their comfort level with it (Bingimlas, 2009).

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Part C: Implementation

C.1 ACCESSIBILITY: Materials support the adaptability of the learning environment and activities meet the needs of all learners (adapted from IMS Global Learning Consortium, 2004).

Curricular materials and instructional methods should allow for flexible instructional media to enable a supportive learning environment for all students (Rose & Meyer, 2002). Accessible systems in the learning environment are designed in ways to accommodate students' background and disabilities. Universal design for learning provides guidelines for designers developing assessments that allow for accurately measuring learning progress among students having a range of disabilities (Mislevy et al., 2013). Researchers have developed design principles to meet diverse student needs so that digital technologies can be adopted to meet the learning needs of these students (Mislevy, et al., 2013; Rose, Meyer & Hitchcock, 2005). It is important to remember that providing equal access to science curricula for students with varying abilities and disabilities also requires collaboration at the teacher level, where support staff can assist students with disabilities in accessing the same material as other students (Dymond et al., 2006).

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C.2 ALIGNMENT TO LOCAL CONTEXTS: Materials support adaptation of curriculum content and activities to the socio-cultural instructional context of use (including the culture, capability, policies, and management infrastructure).

Curricula materials need to be designed so they are adaptable to the socio-cultural background in which these curricula are being used. Fishman and Krajcik (2003) described three challenges that teachers and school organizations must meet in adopting curricular innovations: (1) that the innovation is adaptable to the organization's context, (2) that the organization is able to enact the innovation successfully, and (3) that the organization is able to sustain the innovation. Adapting to an organization's social-cultural and local context includes adapting to the organization's culture, capability, policies, and management (Blumenfeld et al., 2000). Materials that are designed to be adapted to these dimensions are more likely to be successfully implemented and scaled (Penuel, Fishman, Cheng & Sabelli, 2011). Additionally, curricula that allow for the use of problem contexts that are relevant to students and their communities (i.e., local issues) can more powerfully leverage problem- and project-based learning strategies and embed classroom activities in real-world contexts that students are likely to view as important to their lives and potential careers.

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C.3 PROFESSIONAL DEVELOPMENT & LEARNING SUPPORTS: Materials support teachers to implement all activities and make all aspects of equitable education possible, including providing access to new pedagogical frameworks and knowledge (e.g., project-based learning, creating UDL-based access to students with diverse needs, and building support networks for alternative instructional styles, such as small-group based learning) (Dymond et al., 2006).

The Teaching Commission (2004) underscored the importance of taking a multi-faceted approach to providing teachers with professional development, to secure their success at teaching children (Borko, 2004). Studies from across the globe have reinforced this need for continuous and coherent professional development (Villegas-Reimers, 2003). The US National Ed Tech Plan has also emphasized that the potential of online environments and the opportunities they afford teachers to collaborate with each other should be maximized (Office of Educational Technology, 2010). The professional development of teachers is necessary to make all aspects of equitable education possible, including providing access to new pedagogical frameworks and knowledge (e.g., project-based learning, creating UDL-based access to students with diverse needs, and building support networks for alternative instructional styles, such as small-group based learning) (Dymond et al., 2006).

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C.4 EVIDENCE OF EFFECTIVENESS: Research studies or other forms of evidence of effectiveness of instruction are cited.

A clear indicator of high-quality instruction is a body of research documenting the instructions' effectiveness. Effective STEM instruction requires researchers to continue gathering evidence regarding challenges teachers face when implementing curricula (Odom, 2009; Penuel, Fishman, Yamaguchi & Gallagher, 2007). Professional development is a great tool to ensure effective and standardized implementation of sound research-based programming.

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C.5 ACCESS TO MATERIALS & PRACTITIONER SUPPORT: Materials and other user support are available independent of time, language, operating system or cost constraints.

Reform-based science curricula often encompass inquiry-based learning methods, for which science materials are integral to teachers' implementation of these curricula (Schneider & Krajcik, 2002). The key to creating sustainable access to STEM curricular innovations is in generating and building capacity within the school system (in collaboration with teachers and principals) so that the innovations remain in use even after the developer leaves (Fishman & Krajcik, 2003). This is truly attainable when teachers and students have infrastructural support from school systems and support from wider policy initiatives that do not alter the instructional priorities of teachers (Fishman & Krajcik, 2003), helping them retain focus on curricular goals intended by the interventions. Constraints like cost and time should not serve as hindrances for students to use the material (AAAS, 1994). Teachers and students must also have access to the instructional materials and technology needed to implement STEM curricula. Many web-based curricula require dedicated technological infrastructure with access to reliable Internet and digital learning tools (Office of Educational Technology, 2010; Roschelle, 2010).

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C.6 SCALABILITY: All materials and practitioner supports are provided in a way that increasing their use in an educational system is not constrained.

Scalability of programs requires several critical components, first of which is availability of learning materials that students and instructors should be able to access (AAAS, 1994). For online materials, technology-based or enhanced learning environments pose particular challenges to successfully scaling implementation of STEM curricula, particularly when lack of technology infrastructure is a concern. Curricula that have been tested in real-world environments using input from actual users, with refinements to design based on use cases, and which are generalizable, show the most promise for scalability (Clarke & Dede, 2009; Fishman & Krajcik, 2003). Professional development (PD) that is scalable is a critical component of STEM curricular programs that hold promise for scaling (Fishman & Krajcik, 2003; Fishman & Pinkard, 2001). It is important that program developers pay attention to the mode of PD, as online-only PD—while it offers the promise of scale—can pose challenges in terms of the infrastructure needed to implement it and ensure teachers actually engage with the material (Nelson, Ketelhut, Clarke, Bowman, & Dede, 2005).

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The Global STEM Alliance (GSA) is an initiative of the New York Academy of Sciences dedicated to preparing the next generation of STEM innovators for 21st-century careers. With more than 200 partners in 50 countries and regions around the world—including governments, corporations, educational institutions, and nongovernmental organizations—the GSA works to improve access to quality STEM instruction, and to increase the number and diversity of students pursuing STEM careers.

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THE NEW YORK ACADEMY OF SCIENCES
7 World Trade Center
250 Greenwich Street, 40th floor
New York, NY 10007-2157